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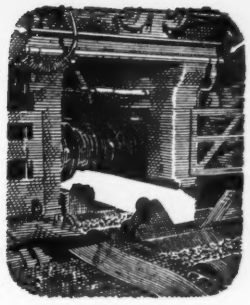

Basic Open-Hearth Practice at Volta Redonda

By L. Cook, A.I.M., M.Inst.F.

SYNOPSIS

The paper gives an account of the plant and operation of the open-hearth shop of the National Steel Company of Brazil. The works, which are situated between the federal capital of Rio de Janeiro and the industrial centre of São Paulo, make a major contribution to the steel production of Brazil.

Some details are given of the raw materials and the refractories used, and the account contains descriptions of furnace design and construction, augmentation of capacities, firing practice, steelmaking procedure, and repair methods. Performance figures and typical heat logs are included.

The paper concludes with a description of extensions under construction and of further plans to increase the annual capacity to one million metric tons of steel. 957

THE plant of the Companhia Siderúrgica Nacional (Brazilian National Steel Company) is situated at Volta Redonda, between the federal capital and port of Rio de Janeiro and the industrial centre of São Paulo.

The Volta Redonda works make a major contribution to the steel industry of Brazil, and the progressive rise in steel production at the plant since the start of operations may be seen from the following:

Year	Steel Production, long tons
1946	84,748
1947	144,239
1948	243,381
1949	300,629
1950	410,508
1951	457,684
1952	468,710
1953	474,754

The figures for 1951–1953 include the production of a small electric furnace. Extensions to increase the plant capacity are under construction.

RAW MATERIALS

The plant is served by the Central Railway of Brazil and ore is hauled 243 miles from the Company's mines at Lafaiete in the State of Minas Geraes. Limestone, dolomite, chrome ore, and bauxite are obtained from various sources within the same state, which lies to the north of the State of Rio de Janeiro in which Volta Redonda is situated. Coal for coking purposes is brought from the State of Santa Catarina in the south, most of the 600 miles of travel being by sea. Additional coal required for blending is imported. Ample supplies of water are drawn from the Paraiba river which runs close to the works.

Representative analyses of raw materials are given in Table I.

PLANT LAYOUT

The main building, 486 ft. long × 199 ft. wide, has a mixer building extension 125 ft. long × 85 ft. wide. Furnace columns are spaced at 108 ft. centres.

The present plant consists of four O.H. furnaces, three stationary and the fourth a tilter. Originally all were of 150 metric tons (147·6 long tons) capacity, but the three fixed furnaces now tap 200 metric tons (196·8 long tons) and the tilter taps 180 metric tons (177·2 long tons).

The furnaces were designed in the first place for firing with mixed blast-furnace and coke-oven gas with atomized tar additions, but oil fuel, with or without cold coke-oven gas, has since been used, and the furnaces have been modified for this method of firing.

Hot metal is received from the 25-ft. hearth dia. blast-furnace in 80-metric-ton (78·7-long-ton) capacity Kling ladles and is stored in a 600-metric-ton (590·5-long-ton) drum-type inactive mixer which is heated with coke-oven gas. All the hot metal is weighed on a weighbridge after leaving the blast-furnace, and all the hot metal drawn from the mixer

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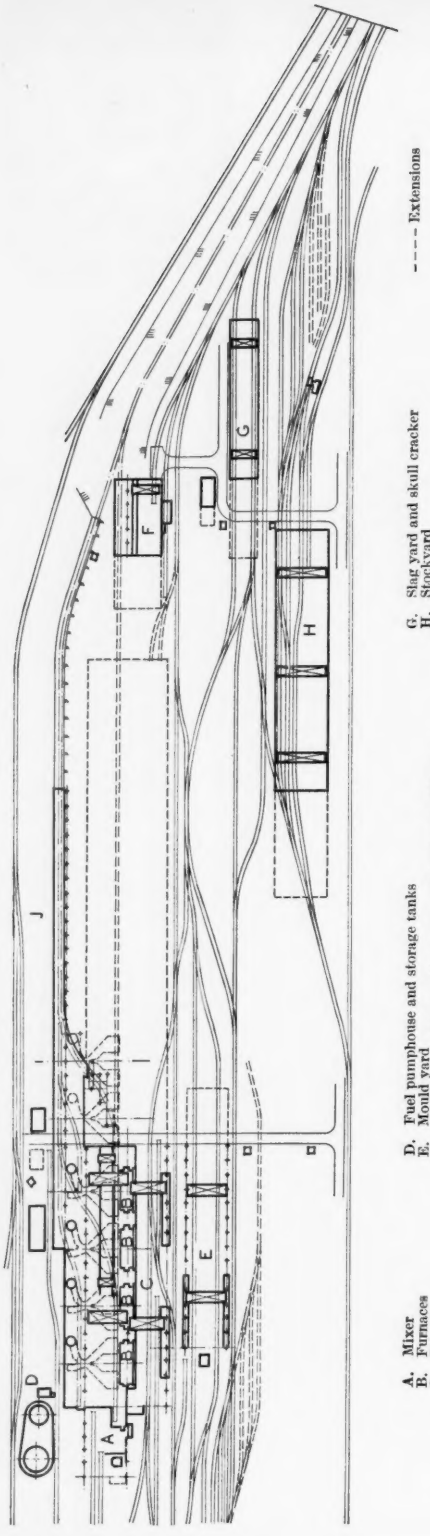


Fig. 1—General layout of department

is weighed on a bridge beneath the hot-metal transfer ladle carriage, the weight being indicated on a dial while the ladle is being filled. Two cranes, each of 250,000 lb. capacity with 50,000-lb. auxiliary hoists, handle the hot-metal ladles.

The cold stock is charged into the furnaces by either of the two Morgan low-type charging machines of 15,000 lb. capacity, the charging boxes being carried on cars running on rails in front of the furnaces. Reserve supplies of furnace additions are held on stands situated between the furnaces. Raw materials are loaded into the charging boxes in the stockyard, which has large bunkers of ample storage capacity.

The stockyard is served by three 20,000 lb. capacity cranes equipped with grab buckets and magnets. All materials—scrap, ore, limestone, etc.—loaded in boxes are weighed on a weighbridge in transit to the charging floor. Pit scrap and iron skulls too large for loading directly into the charging boxes or on to the peels are broken up at the breaker yard, which has a 60,000-lb. crane (fitted with a 20,000-lb. auxiliary hoist) and another 20,000-lb. crane. The breaker-yard structure permits the larger crane to pass over the smaller. Hot open-hearth slag is tipped into a pit beneath these cranes and is loaded when cold through screens into wagons by a grab bucket for transfer to the blast-furnace.

Sheet scrap up to $\frac{1}{8}$ in. thick is bundled into bales in a large press situated in the scrap-preparation extension of the stockyard. Thicker plate scrap is cut into sizes convenient for charging boxes at two large shears. Still heavier steel scrap is flame-cut.

Limestone is calcined and dolomite stone is crushed and sized in a further building, containing large storage bunkers, calcination kilns, jaw crushers, screens, elevators, and silos. The building is served by a 20,000-lb. crane.

The ingots are cast on cars and the casting bay is provided with two cranes, each of 550,000 lb. capacity and fitted with 80,000- and 30,000-lb. auxiliary hoists. A small repair crane with a 32,000-lb. hoist passes over the two larger cranes. Two electrically driven machines are provided for the mechanical capping of ingot moulds.

The mould-preparation bay and storage yard has two 40,000-lb. cranes and an electrically driven car which travels over the moulds for inspection, cleaning, and treatment. Moulds are stripped from the ingots by a 400,000-lb. stripper crane in a separate building adjacent to the soaking pits.

Figure 1 illustrates the general layout of the department and Fig. 2 gives a cross-section of the open-hearth building.*

FIRING

Earlier Arrangements

The policy followed during the earlier days of operation, subject to sufficient supplies of gas being available, was to operate the furnaces with mixed blast-furnace and coke-oven gas carburetted with tar, when the furnaces were new and relatively gas-tight, and to use full tar-fuel firing during the final stages of a campaign.

* The general engineers for the works were A. G. McKee and Company, and the Freyn Engineering Company were responsible for the steelmaking plant.

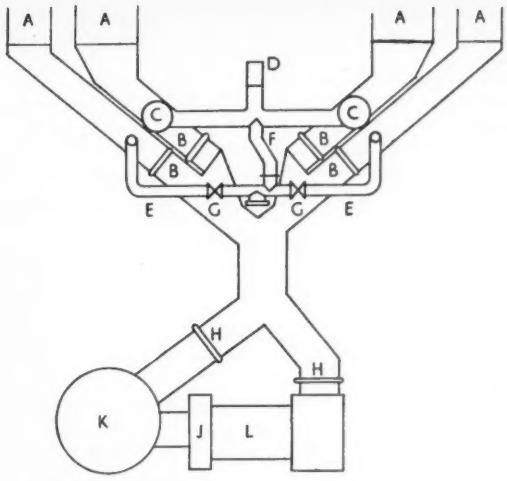
Table I

ANALYSES OF STEELWORKS RAW MATERIALS

Composition, %	Iron Ore	Lime-stone	Raw Dolomite	Bauxite	Chrome Ore
SiO_2	0·69	1·38	1·18	4·82	8·50
Al_2O_3	0·87	...	...	52·31	13·79
Fe	68·51	...	...	...	18·00
Fe_2O_3	...	...	...	11·82	...
P	0·052	0·04	...	...	...
S	0·020	0·033	...	...	...
CaO	...	55·32	31·03	...	...
MgO	...	...	19·60	...	8·63
Cr_2O_3	...	...	...	...	40·53

From the first, the shop was therefore equipped with circulatory pipes, steam lines, and the usual arrangements for using liquid fuel. In addition, at each furnace a short main, kept closed with a goggle valve during mixed-gas firing, connected the mixed gas main with the air main so that it was possible, at the changeover to full liquid-fuel firing, to bypass part of the incoming air from the fan into the checker chambers previously used to preheat the mixed gas, by removing the goggle plate and by sealing off any gas flow with a further plate. Reversals in the direction of flow of the by-passed air were made with the Linatex-lined valves and the reversing dampers of the mixed-gas system, the proportions of air distributed between the 'gas' and the air checkers being controlled by a screw adjustment regulating the height of lift of the air mushroom valves. The arrangement of the valves and dampers is shown in Fig. 3.

When a change from mixed-gas firing to full tar firing was made, the short carburetting burners were removed and replaced with longer artillery-type burners that were inserted into the gas ports through the end wickets. Tar fuel gave a flame of bright-



A. Regenerators
B. Reversing dampers
C. Air reversing valves
D. Air fan
E. Mixed-gas main
F. Tube connecting mixed-gas main with air main
G. Linatex reversing valves
H. Dampers
J. Boiler fan
K. Chimney
L. Waste-heat boiler

Fig. 3—Arrangement of valves and dampers

ness and intensity, and good production rates were obtained until choking of the checkers and flues occurred.

Adoption of Oil Firing

Various factors led to the adoption of a full oil or oil plus coke-oven gas firing programme. The

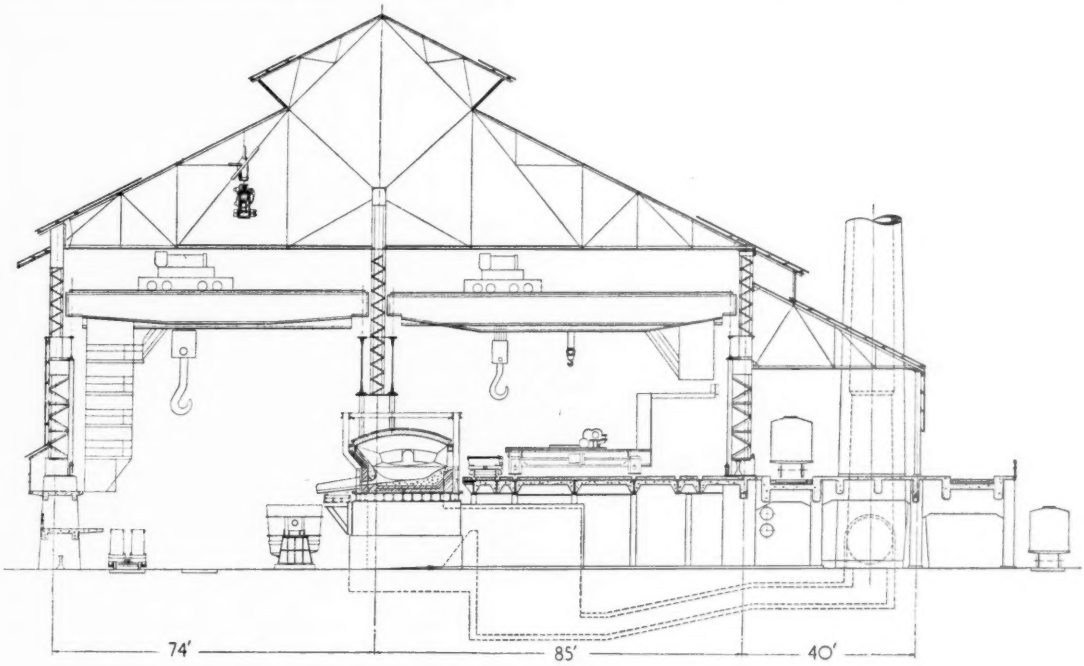


Fig. 2—Cross-section of open-hearth building

increased demand for both blast-furnace and coke-oven gas elsewhere on the plant, the use of tar in other directions, and the need for the maximum production of steel influenced the decision to change to a suitable fuel that was entirely free from plant limitations of supply.

At first, methods similar to those previously used for tar firing were used and the burners were inserted into the water-cooled gas-port tunnels of the Venturi furnaces designed for mixed-gas firing, but, as soon as possible (at furnace rebuilds), the fixed furnaces were modified to a conventional oil-fired furnace design, the bath capacities also being increased at the same time.

Present Oil-Firing Arrangements

Oil is stored in two storage tanks with a combined capacity of 440,000 gal. (Imperial), and supplies of fuel oil are received in large motor tank cars that arrive by road from Rio de Janeiro. Additional storage capacity is available on the plant.

Two rotary-screw pumps, each of 83·3 gal. (100 U.S. gal.) per min. capacity are available for unloading the oil. The pumphouse also contains four rotary-screw circulatory pumps, each of 16·7 gal. (20 U.S. gal.) per min. capacity, for supplying the oil to the furnaces.

Oil is carried in 3-in. mains, lagged with steam pipes, to the furnace branch lines, and similar mains return excess oil to the tanks; 2-in. pipes conduct the oil and steam from the supply mains to the control stands at each furnace. The oil is delivered from the control stands to the burners *via* 1½-in. lines. The oil delivery temperature is maintained at 70° C. by a thermostatic-controlled heater situated after the circulatory pumps. The pressure in the oil main is 200 lb./sq. in.

The temperatures and pressures of the steam as measured at the control stands are 220–250° C. and 125–135 lb./sq. in., respectively; 1½-in. steam lines connect the stands with the burners. Superheaters are installed in each furnace main flue in addition to the usual superheating arrangements at the boilers.

The oil reversals and volume controls are made with Nordstrom lubricated valves. Steam reversals are made through Nicholson three-way valves. Bypass lines provide uniform flows of 'dead-end' steam. Additional valves are furnished at the stands for steam purging.

Crowe combination gas and oil artillery burners are used for firing the furnaces. In each burner, the emulsified mixture of oil and steam passes through a 1-in. dia. tube which is surrounded by a tube of a slightly larger diameter. Steam is passed through the

Table II

FURNACE DIMENSIONS

	Original Furnaces: Gas-fired, 150 metric tons (147·6 long tons) capacity		Modified Fixed Furnace: Liquid-fuel type, 180 metric tons (177·2 long tons) capacity*
	Tilter	Fixed	
Furnace upper structure: Length	90 ft. 6 in.	84 ft. 0 in.	75 ft. 0 in.
Width	22 ft. 1 in.	23 ft. 11 in.	23 ft. 11 in.
Hearth dimensions, foreplate level, brick line: Length	48 ft. 9⅜ in.	48 ft. 0 in.	49 ft. 6 in.
Width	17 ft. 0 in.	17 ft. 7½ in.	18 ft. 0 in.
Hearth area, foreplate level, brick line ($l \times w \times 0{\cdot}9$)	747 sq. ft.	761 sq. ft.	802 sq. ft.
Hearth area at brick line per long ton of steel	5·06 sq. ft.	5·16 sq. ft.	4·53 sq. ft.
Depth of working hearth at centre opposite the taphole	3 ft. 0 in.	3 ft. 0½ in.	3 ft. 3 in.
Elevations of roof above foreplate: Main roof, centre line to spring line	4 ft. 7 in.	4 ft. 7 in.	4 ft. 7½ in.
Main roof, centre line: max. rise	7 ft. 1½ in.	7 ft. 4 in.	7 ft. 4½ in.
Knuckle: max. rise	5 ft. 1 in.	4 ft. 2 in.	...
End roof: max. rise	9 ft. 10⅜ in.	10 ft. 0 in.	9 ft. 4½ in.
Roof lengths, parallel to foreplate: Main roof flat	35 ft. 0 in.	28 ft. 6½ in.	48 ft. 0 in.
Main roof slope (one side)	8 ft. 6 in.	9 ft. 8½ in.	...
Knuckle + joint (one side)	2 ft. 3 in.	...	...
End slope (one side)	7 ft. 0 in.	8 ft. 6 in.	8 ft. 6 in.
Hood (one side)	5 ft. 6 in.	5 ft. 0 in.	5 ft. 0 in.
Throat widths: Top	13 ft. 6 in.	13 ft. 4½ in.	14 ft. 6 in.
Bottom	12 ft. 0 in.	11 ft. 4 in.	11 ft. 6 in.
Cross-sectional areas: Above foreplate at centre	115 sq. ft.	129 sq. ft.	130 sq. ft.
Throat at knuckle	41 sq. ft.	41 sq. ft.	...
Throat at junction of main roof and ramp	...	...	81 sq. ft.
Gas port at nose	4 sq. ft.	4 sq. ft.	...
Gas uptake	16 sq. ft.	16 sq. ft.	...
Air uptakes (one end)	66·5 sq. ft.	66·5 sq. ft.	84 sq. ft.
Slag pockets: Slag capacity (both ends) excluding false walls: 7 ft. 0 in. high	3668 cu. ft.	3406 cu. ft.	...
7 ft. 8 in. high	...	...	4150 cu. ft.
Regenerator chambers: Length	24 ft. 0 in.	24 ft. 0 in.	24 ft. 0 in.
Width (gas)	8 ft. 0 in.	8 ft. 0 in.	8 ft. 0 in. (used for air)
Width (air)	12 ft. 0 in.	12 ft. 0 in.	12 ft. 0 in.
Height of checkerwork above arches	19 ft. 9 in.	19 ft. 9 in.	19 ft. 9 in.
Volume of checkerwork (one end) per long ton of steel	61·8 cu. ft.	61·8 cu. ft.	51·5 cu. ft.
Checkerwork: Size of vertical openings	7½ in. × 7½ in.	7½ in. × 7½ in.	7½ in. × 7½ in.
Free area of checkers (one end)	257 sq. ft.	257 sq. ft.	257 sq. ft.
Heating surface of checkers (one end) per long ton of steel	254 sq. ft.	254 sq. ft.	211 sq. ft.
Height of arches beneath checkers: Max.	3 ft. 9 in.	3 ft. 9 in.	3 ft. 9 in.
Min.	2 ft. 7 in.	2 ft. 7 in.	2 ft. 7 in.

* The dimensions of the 180-metric-ton liquid-fuel fixed furnace are those used at the initial modification. Subsequent modifications, including the further augmenting of the capacity, are described in the text

annular space between the tubes, the supply being derived from a separate line. The tubes are positioned down the centre of the coke-oven gas burner, which is a water-jacketed tube with an internal dia. of 4 in. Cooling water is supplied to the nose of the water jacket through an external pipe, the water exit being at the rear end of the burner situated outside the furnace. A further steam connection allows the gas-burner passage to be cleaned out at suitable intervals.

Atomization is carried out in a chamber at the rear of the burner, the steam impinging at an angle on a jet of oil issuing from the $\frac{1}{4}$-in. orifice. Adjustments to the flame can be made with a screw which alters the position of the oil jet within the chamber. The direction of a burner can be controlled in both an horizontal and a vertical plane.

Firing rates of up to 400 gal. (Imperial) of oil per hr. are used during the earlier stages of a heat. Coke-oven gas in quantities of up to 700 cu. ft./min. is used to supplement the oil fuel during charging and melting. When additional coke ovens came into operation in mid-1953, this use of gas became possible as a standard practice instead of, as formerly, being limited to occasions when supplies were available to the department (usually during week-ends). The coke-oven gas is received from the waterless-seal holder at a pressure of 16 in. W.G.

Fuel Analyses and Properties

Typical compositions and values are:

	wt.-%
Oil	
Carbon	85·48
Hydrogen	10·34
Nitrogen	0·77
Oxygen	1·72
Sulphur	1·69
Specific gravity at 30° C.	0·972
Net calorific value, B.Th.U./lb.	17,626
Viscosity, Saybolt Furol at 122° F., sec.	166

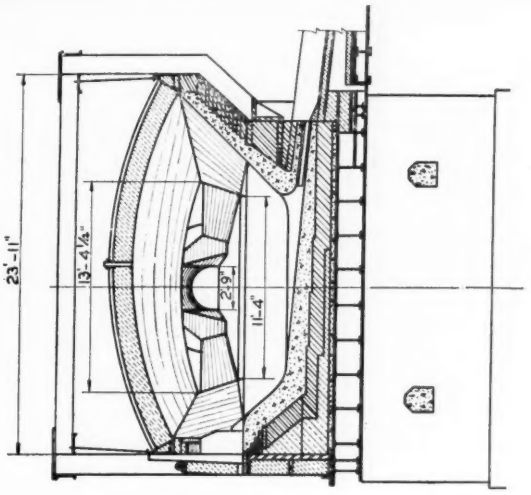
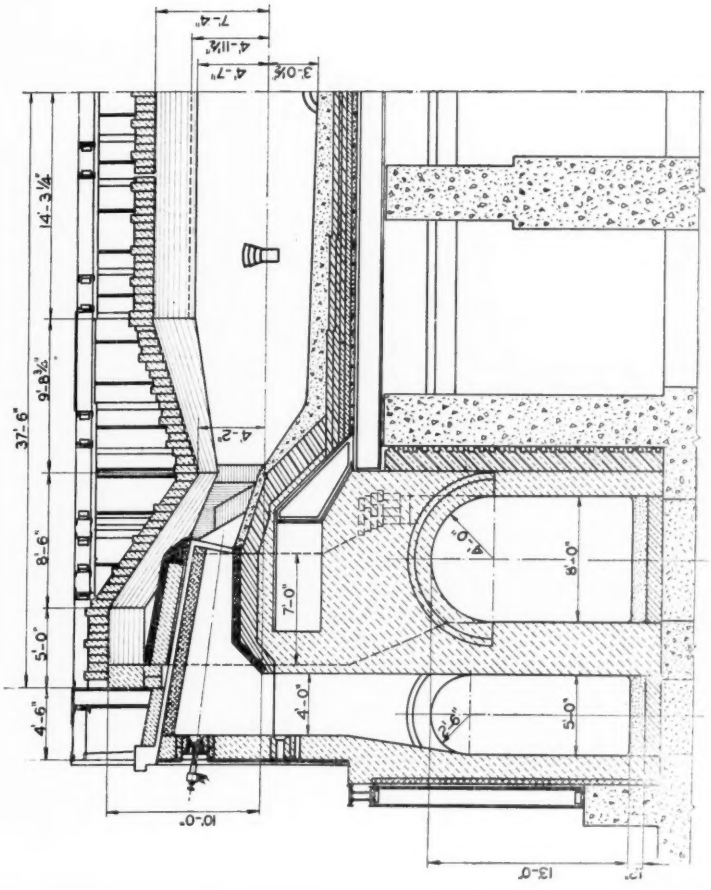


Fig. 4—Gas-fired 150-ton fixed furnace



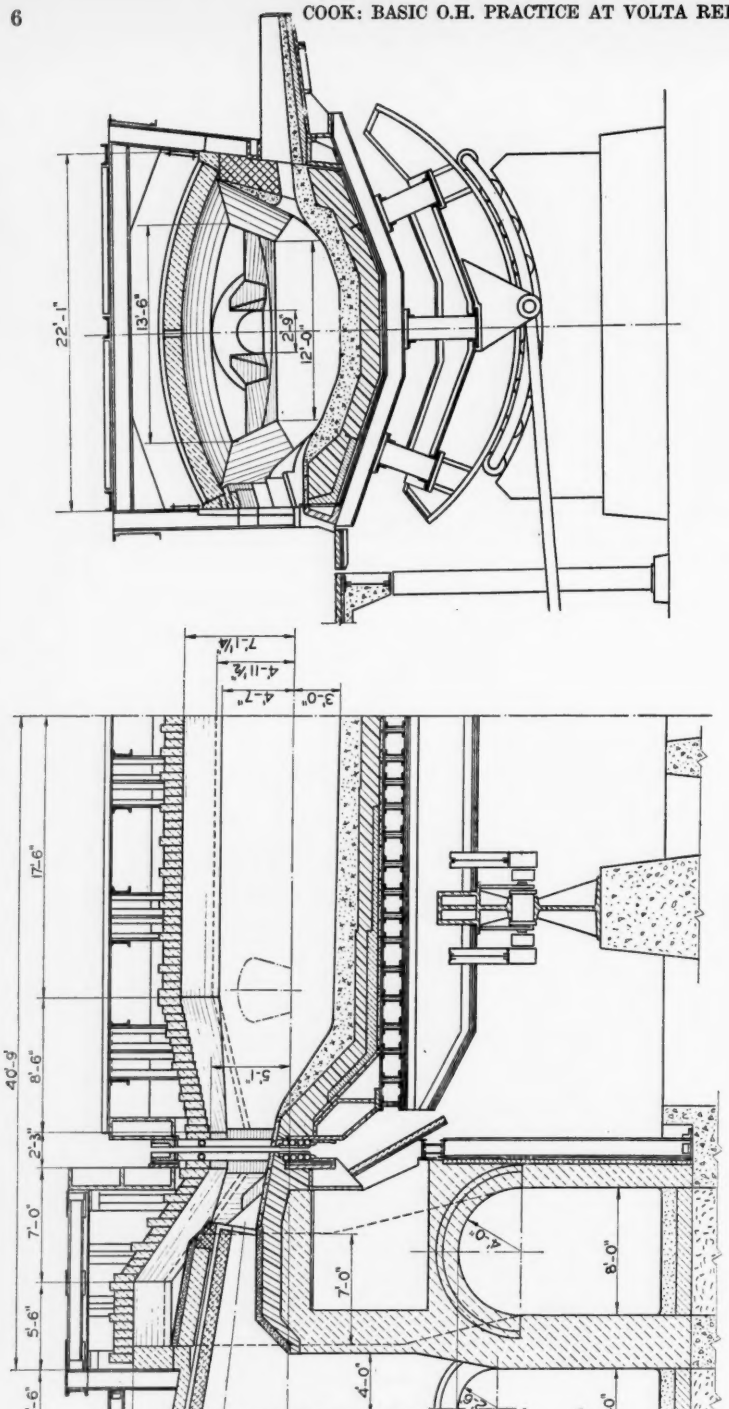


Fig. 5—Gas-fired 150-ton tilting furnace

	vol.-%		vol.-%
Coke-Oven Gas			
CO_2	1·5	CH_4	26·3
H_2	58·7	C_nH_n	2·6
O_2	0·2	N_2	4·4
CO	6·3		

Net calorific value
490 B.Th.U./cu. ft.

FURNACE DESIGN AND MODIFICATIONS

The designs of the former gas-fired fixed furnaces and tilter are shown in Figs. 4 and 5, and the design for the modification of the fixed furnaces in Fig. 6. Furnace dimensions are given in Table II.

The furnaces were converted at convenient intervals during 1950–1951. The alterations made to convert the 150-metric-ton (147·6-long-ton) fixed furnaces designed for gas firing into 180-metric-ton (177·2-long-ton) oil-fired furnaces were:

(i) The slag-pocket division walls were removed to give single slag pockets of increased capacity, the fantail arches leading to the retained twin checker chambers being supported on piers extending into the slag pockets

(ii) The water-cooled brick-lined gas-port tunnels were removed and the furnace ends were shortened

(iii) The gas uptakes were eliminated and the twin air uptakes were enlarged to give them a total cross-sectional area approximately equivalent to the previous total cross-sectional area of the gas and air uptakes

(iv) The foreplate sill levels were raised 2½ in. and the hearth ends were strengthened

(v) Main roofs were raised 3 in. and roof lines were modified.

Other changes were made from time to time after the conversions. These included the replacement of all brick door arches with archless door openings, alterations to the checker brickwork, raising the heights of the flues beneath the checkers, and the transfer of the cooling-water open discharges from the fronts to the

ends of the furnaces. In 1952, the foreplate sill levels of the fixed furnaces were raised an additional 2½ in. to accommodate 200-metric-ton (196·8-long-ton) heats. The roofs and skews were also raised by this amount.

Modifications made to the tilting furnace included (i), (ii), and (iii) above, together with alterations to the cooling-water discharges and the replacement of brick door arches with arch-less door openings. At this furnace the original roof lines have been retained.

A general view of the furnaces from the tapping side is given in Fig. 8.

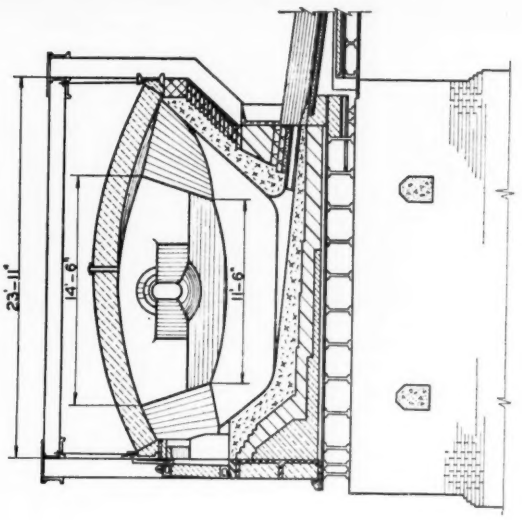


Fig. 6—Liquid-fuel-fired 180-ton fixed furnace

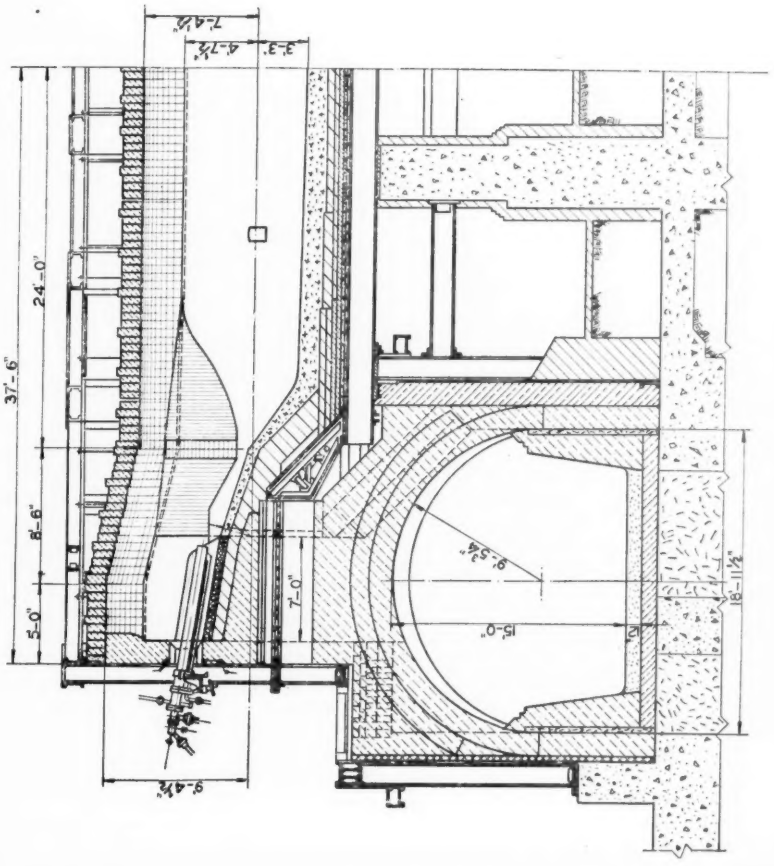
FURNACE BRICK REFRACTORIES

Silica Bricks

Brazil is fortunate in possessing many sources of excellent refractory raw materials, and the silica bricks produced within the country and used at the plant are at least equal in performance to any of the imported bricks of a similar type that have been tried.

The following are some details of Brazilian silica bricks:

Analysis:	SiO_2	96·00%
	Al_2O_3	1·10%
	Fe_2O_3	0·81%
	CaO	1·86%
	MgO	0·18%
Apparent porosity		24·80 vol.-%
Specific gravity (apparent)		1·78
Specific gravity (real)		2·34
Reversible expansion (20–1000° C.)		1·28%
Permanent expansion at 1500° C.		0·40%
Refractoriness		1680° C.
Refractoriness under 2 kg./sq. cm. (28·4 lb./sq. in.) load:		
Start of deformation		1645° C.
40% deformation		1650° C.
Cold crushing strength		235 kg./sq. cm. (3342 lb./sq. in.)



Some trials have been made with super-duty or silica bricks of lower alumina content. When used in roof construction as ribs with intermediate rings of ordinary silica bricks, the super-duty bricks projected slightly from the underside roof surface after about 50 heats. Two main roofs constructed entirely of super-duty bricks had, however, lives less than the shop average.

Two main roofs of ' zebra ' construction, employing part rings of steel-cased unfired basic bricks, also had lives less than the average.

Burnt Magnesite Bricks

An analysis of these Brazilian-produced bricks is:

SiO_2	4·0%	CaO	Trace
Al_2O_3	2·0%	MgO	84·7%
Fe_2O_3	8·5%		

The bricks possess a good resistance to spalling and have given excellent results in replacing imported basic bricks of all types, burnt or chemically bonded, metal-sheathed or plain, in the construction and repair of uptakes, bridge walls, wing walls, bulkheads, and front and back walls.

Checker Firebricks

The analysis and properties of the nationally produced bricks are:

Analysis: SiO_2	56·50%
Al_2O_3 (inc. TiO_2)	41·80%
Fe_2O_3	1·85%
CaO	0·10%
MgO	0·21%
Apparent porosity	23·50 vol.-%
Specific gravity (apparent)	2·05
Reversible expansion (20–1000° C.)	0·47%
Refractoriness	1745° C.
Refractoriness under 2 kg./sq. cm. (28·4 lb./sq. in.) load:	
Start of deformation	1460° C.
5% deformation	1520° C.
10% ,,	1560° C.
20% ,,	1600° C.
40% ,,	1630° C.
Cold crushing strength	285 kg./sq. cm. (4054 lb./sq. in.)

REFRACTORY CONSUMPTION, ROOF LIVES, AND CAMPAIGNS

The consumption of refractories at the furnaces during 1953 was:

Silica brick	15·59 lb. per long ton of ingots
Basic brick	8·22 ,, ,, ,, ,, ,, ,,
Firebrick	7·50 ,, ,, ,, ,, ,, ,,
Total	31·31 ,, ,, ,, ,, ,, ,,

During 1953, the average roof (centre main roof from ' knuckle ' to ' knuckle ') life was 128 heats. Ramps and end roofs last the full campaign from one partial general repair to another. The campaign average during 1953 was 263 heats. Main roofs are usually patched only once.

FURNACE CONSTRUCTION

Roofs

The main roofs are now ribbed at every third ring, and the ramps and the end roofs at every fourth ring; 15-in. and 18-in. roof bricks are used for the main construction and 18-in. and 22-in. bricks for the offset portions that now extend along the main roofs to a width of 5 ft. from the rear skews and 2 ft. from the front skews.

The skewback channels, which carry the special-shaped skewback bricks, are suspended from the rigid superstructures by bolts in the usual way.

Front Linings

The conditions arising from the increases in heat sizes, together with the firing and furnace-pressure practice used, caused difficulties with the original type of front lining, which was constructed with courses of silica bricks over the four courses of burnt chrome bricks above the foreplate level and with silica-brick arches spanning the door openings.

Varied methods of construction with various materials were tried, but the front-wall life remained unsatisfactory until the present construction was used. The front walls are now built up entirely with burnt magnesite bricks, each course being separated with steel sheets. The heavier sheets used at every fourth course project outwards, the projecting portions being slotted for the use of anchoring bars. Flat coolers, 8 in. wide × 3½ in. deep, are installed beneath and are spot-welded to the skewback channels. These coolers, five in number, extend across the front of each furnace, and the former door arches have been abolished.

At the tilting furnace, the front walls are built with the brick courses inclined upwards at an angle to the bath.

Back Walls

The sloping back walls are built up with burnt magnesite bricks and the brickwork is protected by a monolithic covering of magnesitic material which is cold-rammed into position at a repair.

Door Frames and Doors

The water-cooled frames have been altered to give enlarged door openings 50½ in. high × 51½ in. wide. The frames are fastened to angles attached to the furnace buckstays, the upper part of each frame being held in position with cottered pins. The bases of the frames are located in slots in the cast-steel foreplates. Each door and frame can be lifted together in one assembly. The water-cooled doors are brick-lined, experiments made with rammed door linings showing no advantage over the usual method.

Uptakes, Bridge Walls, and Bulkheads

Basic bricks are used in the construction of these parts. At each uptake, built-in steel angles welded to the furnace steel structure relieve the supporting arches of some of the weight of the upper brickwork. Horizontal cooling pipes built into the brickwork preserve the furnace bridge walls. Furnace-end bulkheads, now built with burnt magnesite bricks from below the charging-floor level, often outlast a roof without requiring any repair. Steel separating sheets are used between the brick courses in uptake and end-bulkhead construction.

Burner Openings

The burners are inserted through openings that are provided with water-cooled arches.

Furnace Hearths

The pans are constructed from ¾-in. plates and are

supported on 20-in. beams. Chill boxes extend across the width of each furnace beneath the end slopes. At the fixed furnaces, each box is joined in the centre, **T**-wise, to a steel channel which passes through a brick tunnel in each burner block to connect with the end framing.

The hearth plates are covered with a 3-in. layer of insulating cement above which is laid a 4½-in. course of first-quality firebricks, except in the taphole area, where burnt chrome bricks are used throughout. Above the firebricks, courses of burnt chrome bricks are laid to give a thickness at the centre of 10½ in. of this material.

The monolithic hearth consists of 7 in. of rammed cold-setting magnesitic material over which layers of magnesite are sintered. A completed hearth has a total thickness of 32½ in. in the centre opposite the taphole.

An analysis of the ramming material is:

Ignition loss	0·7%	Cr_2O_3	2·5%
SiO_2	8·0%	Na_2O	1·0%
Fe_2O_3	3·2%	CaO	13·7%
Al_2O_3	2·7%	MgO	67·1%

The bulk density is 139 lb./cu. ft. and the rammed density is 160 lb./cu. ft.

Slag Pockets

False walls of silica brick are constructed with care, as the ease of removal of the slag depends on their remaining in position. A sand-filled brick flue is constructed down the middle of the floor of each pocket for use, during repairs, in connection with a large crane-handled lever.

Checkers

At the fixed furnaces with liquid-fuel firing, and in spite of the routine use of steam and compressed air, dust deposits caused clogging difficulties with the original checkers, which were constructed with 10 in. × 4½ in. × 2½ in. interlocking bricks in the lower 50 courses and similar-sized ordinary-shape bricks in the upper 13 courses to give 7½ in. × 7½ in. openings. Sagging of the upper courses occurred at times, making the continued use of lances difficult or impossible.

Accordingly, changes were made. Beginning with furnace 2 and following with the other fixed furnaces as they became due for a general repair, the checkerwork was built up with larger and more sturdy bricks (15½ in. × 4½ in. × 3½ in.) to give openings of 12 in. × 12 in., and the rider arches beneath the checkers were raised to give a uniform height of 4 ft. from the floor to the crown in the checker flues.

Metering of the air passing into the former gas checkers was installed, in addition to the usual metering of the total air flow, so that it was possible to divide the flow of air into the checkers in the proportion of their respective heating-surface areas.

On a long-term view, these changes have proved beneficial. Effects arising from the loss of some of the heating-surface area appear to have been more than offset by improvements in other directions. Campaign lives have been lengthened, and checker lives have been improved immensely. Apart from the routine renewal of the upper courses of checkers made at every partial general repair, and apart from a replacement of checkers in one chamber at furnace 4 after damage by slag penetration and the replacement of a part of the checkerwork in one chamber at furnace 2, all the checkers constructed with the larger openings are, up to the present (31st December, 1953) in a good condition, having made the following tonnages:

Furnace 2	346,344 long tons
Furnace 3	216,538 ,, ,,
Furnace 4	259,434 ,, ,,

Exit main flue temperatures are about 600° C.

At the tilting furnace, choking difficulties have never been particularly pronounced, and the original type of checker with 7½ in. × 7½ in. openings has been retained at this furnace. The checkers installed towards the end of 1949, apart from the renewal of the upper courses, have had only replacements in the east chambers. During this time the furnace has made to date 440,000 tons of steel.

Checker Chambers

The walls of all the chambers are lined with insulating bricks, and the outer walls are plated. Chamber roofs are covered with diatomaceous material and the bulkheads are sprayed with vermiculite. Every care is taken to keep the chambers as airtight as possible.

REVERSALS, FANS, STACKS, AND WASTE-HEAT BOILERS

Reversals of the valves and dampers are made by electric-motorized systems, 10 sec. being taken to complete a cycle. The water-cooled dampers and frames are angled in the flues towards the checker chambers.

At each furnace the air for combustion is delivered by a constant-speed fan with a rated capacity of 15,000 cu. ft./min. at 5 in. W.G., which is driven by a 20-h.p. motor. The volume of air admitted is regulated by a butterfly valve connected to the oil-pressure cylinder of the Askania control.

Alternative paths leading from the main flues are provided and the waste gases may be exhausted *via* the fire-tube waste-heat boilers or direct to the chimney stacks. Movable louvres in the ducts between the exhaust fans and the stacks are connected to the furnace-pressure controls through oil-pressure systems. The waste-heat boilers are provided with superheaters and the 896 2-in. dia. fire tubes of each boiler have a total heating surface of 7600 sq. ft.

Exhaust fans are rated at 42,000 cu. ft./min. capacity at 525° F., and the 175-ft. stacks have internal diameters of 10 ft. 7 in. at the bases and 6 ft. 4 in. at the summits.

INSTRUMENTS AND CONTROLS

The furnace controls are housed in steel cabins fronted with fluorescent-lamp-lit panels upon which the instrument dials and control switches are mounted. Pressure for each Askania oil-jet system is provided by pumps driven by electric motors, both A.C. and D.C. types being installed and coupled with the respective sources of supply. In the event of failure in the usual form of power supply, the alternative motor is started automatically.

On each panel are mounted the following instruments:

Coke-oven-gas flow integrating recorder
Oil-flow indicator
Oil-flow integrating recorder
Total air-flow recorder
Air flow to the ' gas ' checkers recorder
Furnace-pressure recorder
Furnace-pressure regulator
Two-point air and gas pressure recorder
Electric clock
Four-point flue-temperature recorder
Roof-temperature recorder and warning signal
Three-point air-checker temperature recorder and reversal control
Two-point ' gas ' checker temperature recorder
Combustion regulator
Selector and reversal switches and valve controls.

Other instruments previously in use during mixed-gas operation and now no longer required have been removed for use elsewhere on the plant. Adjacent to the panel are the door-operating switches and the screws for adjusting the heights of the air reversal dampers.

Furnace reversals are not automatic; alarm signals operated by a time-setting or a temperature-difference device are provided. Metered oil consumption is checked periodically against oil-stock consumption.

Roof-Surface Temperature Measurement

Both types of radiamatic sighting methods are used on the plant for roof-surface temperature measurement. The roof-block method is used at the tilting furnace and the open-tube method at the fixed furnaces. Both methods have disadvantages; the roof-block target tubes and inserts tend to burn out and maintenance may become difficult or hazardous during the later stages of a roof life, whilst the open tubes situated in the back walls of the furnaces tend to become obstructed by occasional drippings from the roofs and skews, or by dolomite projected from the fettling machine. Any type of roof pyrometer requires frequent checking if any reliance is to be placed on the indicated temperatures, and shop experience has shown that, although a single pyrometer which can give a relative temperature of a local portion of a comparatively large roof area is a useful instrument, it is by no means a substitute for the constant visual attention of an alert furnaceman, especially when high-calorific-value fuels are used.

Furnace Pressures

The automatic control of furnace pressure is now recognized to be of great value in furnace operation. By its use pressures can be maintained at selected values, found by experience to be most suitable, for whole campaigns or until the choking of the passages interferes with the flow of waste gases beyond the point of control.

The following is the roof-pressure practice used in the shop:

Charging and melting period	2·2–2·4 mm. W.G. (0·087–0·095 in. W.G.)
Period from starting to charge hot metal to the melt	1·8–2·0 mm. W.G. (0·071–0·079 in. W.G.)
Melt-to-tap period	2·0–2·2 mm. W.G. (0·079–0·087 in. W.G.)

The values are ' true ' values, due compensation being made at the instruments.

Air/Fuel Proportioning

With the high percentages of hot metal used in the charges, the air/fuel proportioning is carried out at three levels.

As the result of a large number of tests made over many heats, a base air/fuel-oil value was selected approximately equal to 193 cu. ft. (N.T.P.) of dry air per lb. of oil. This value is used during the charging and heating of the cold stock and also during the final stages of a heat. The proportion of air is increased by 10% in the period immediately following the introduction of the hot metal. During the period of the main reactions, an increase of 25% over the base value is used.

The air/fuel-oil proportions are maintained automatically at the values set on the dials. Adjustments are made during the use of supplementary coke-oven gas. Frequent routine waste-gas analyses are made for checking purposes.

The Mixer

The mixer is lined with first-quality firebricks laid over the insulation course that covers the shell. Replaceable brick-lined rings are provided for the hot-metal charging hole.

Some replacement of brickwork is required around the spout, at the hot-metal level, and at the charging hole every 4–5 months. Coke-oven gas, burnt in Bloom long-flame burners, is used for heating.

Hot Metal

Analyses of hot metal received during a representative period are shown in Fig. 7.

OPERATIONS

Stockyard

Limestone and ore are loaded from large-capacity bins into the charging boxes carried on cars, with grab buckets attached to the cranes. Each car holds four cast-steel boxes, each with a capacity of 35 cu. ft.

The average weights of materials carried per box are as follows:

Limestone	1·309 long tons
Iron ore	2·313 ,, ,,
Lime	1·043 ,, ,,
Heavy scrap	3·553 ,, ,,
Light scrap	0·805 ,, ,,
Pig iron	3·051 ,, ,,

Scrap loading has become more difficult with the increased proportions of sheets and light plates that are being manufactured on the plant and, in spite of the scrap-preparation equipment that has been added, the average weight of scrap carried per car has fallen from 5·27 tons in 1947 to 3·93 tons in 1953.

Furnace door openings have been enlarged and additional cars have been acquired but, from the point of view of charge handling, the shortage of heavy scrap is the main factor in the problem.

In the near future, the boxes will be loaded with limestone and ore from bottom-discharged overhead bins and the stockyard cranes will be used entirely for the preparation and loading of scrap. The weights of all charging materials in transit to the open-hearth

furnaces are printed on tickets during the passage over the weighbridge. The tickets accompany the drags to the charging floor.

Furnace Hearth Maintenance and Repairs

	Burnt Dolomite	Imported Magnesitic Hearth Refractory
SiO_2, %	2·69	10·30
Al_2O_3, %	...	3·96
Fe_2O_3, %	...	9·59
CaO, %	53·49	20·52
MgO, %	34·93	55·63
R_2O_3, %	7·01	...
Ignition loss, %	1·58	...
Screen Size, mm.		
+ 10	0·0%	0·0%
− 10 + 1	97·0%	86·5%
− 1	3·0%	13·5%

Burnt dolomite, bought from outside the plant, is used for routine hearth maintenance below the slag line and for erosion at the slag line, and crushed and screened raw dolomite is used for routine slag-line maintenance, back-wall fettling, and banking-up. Deep holes are repaired with the imported hearth material. After every sixth heat a little extra time is taken to shape up the bottom, dress the banks, and carry out a short general preventive repair.

A fettling machine is used for fettling the banks. A compressed-air 'gun' is used to project dry refractory material up to the higher portions of the sloping back walls.

Compressed air is used to remove liquid from holes in the bottom. Tapholes are repaired in the usual way, using steel pipes of the desired taphole diameter and a moistened mixture of magnesitic material and cement.

Table III

INFLUENCE OF PROPORTION OF HOT METAL

Hot Metal in Charge, %	No. of Heats in Group	Av. Production, long tons/hr.
51–55	1	18·9
56–60	7	15·4
61–65	13	17·2
66–70	14	17·8
71–75	14	17·9
76–80	20	17·4

The heats, all soft rimming steels, were made in sequence at one furnace. For the purpose of comparison, the heats were 'screened' so as to include only those with the following qualifications:

(i) Heats with not more than 1 hr. from finishing the previous tap to the start of charging

(ii) Heats with not more than 2 tons of skull

(iii) Heats with not more than 10 tons of cold pig iron in the charges.

The percentage of hot metal in the charge is

$$\frac{\text{Weight of hot metal charged} \times 100}{\text{Total weight (scrap + pig + hot metal)}}$$

and the rate of production is

$$\frac{\text{Weight of steel tapped}}{\text{Tap-to-tap time}} \text{ tons/hr.}$$

Charges

Charges with standard proportions of scrap, hot metal, and (in some cases) cold pig iron are used. These charges, which are suited for various shop conditions and supplies of material, are ordered by code number.

The highest hot-metal/scrap proportion is used when one furnace is under repair and ample supplies of hot

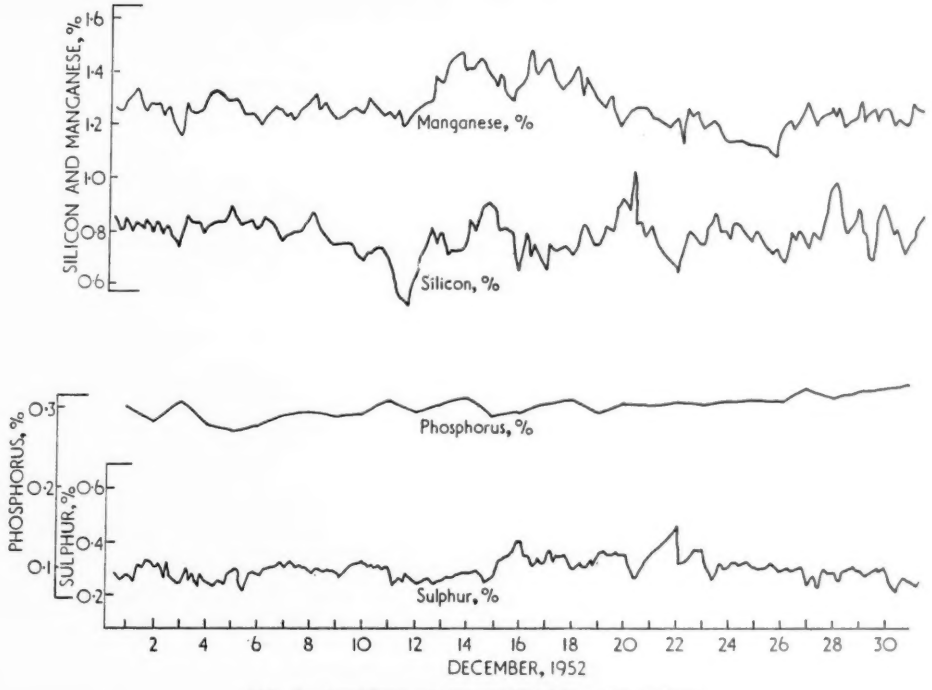


Fig. 7—Analyses of hot metal from the mixer

metal are available. The influence of the proportion of hot metal used is indicated in Table III.

Ore charge amounts are estimated with the aid of a table based on the weight and analysis of the iron to be charged. Compensation is made for any proportion of cold iron ordered. Adjustments are made for melt carbon aims, current melt tendencies, and for heats after brick repairs.

Charging

Charges carried on cars in front of the furnaces and handled by modern low-type non-swivel chargers can be charged rapidly, provided that supplies of full boxes are furnished at a suitable rate. Long strings of cars constituting a charge assembly, the boxes of which contain only fairly low weights of scrap, require the exercise of ingenuity in arranging and manœuvring the cars, especially when adjacent furnaces are being charged or fettling is in progress, to avoid delay and to keep up the desired rate of charging.

Studies have been made of the various circumstances that arise and diagrams have been prepared and given to the operators concerned showing recommended arrangements, the number of cars to be positioned before each particular furnace, and the appropriate shunts.

Charging begins with a run of light scrap or limestone on the bottom, according to the circumstances. When light scrap is charged first, it is followed by limestone. After the limestone, ore is charged, followed by the rest of the limestone. Scrap is then charged. Any iron scrap or cold pig iron used is placed on top of the steel scrap.

Charging-time aims are given, and account must be given of any delay. The shop average time for charging the cold stock is 64 min.

Heating Cold Stock

Shop studies have established the importance of the time taken to heat up the cold stock before the introduction of the hot metal. Optimum times were indicated for normal circumstances that did not vary a great deal with reasonable variations in the amounts of steel scrap charged. To obtain the maximum production rate, it is important that the hot metal should be given on time and that the furnace and its contents should be ready for it; *i.e.*, the furnace should be hot (roof-pyrometer reading 1600° C.) and incipient melting of the scrap should be taking place.

A charge that is too cold when the hot-metal addition is made will have a poor flush-off, the melt slag will be lacking in basicity so that extra additions of lime or limestone will be required, and the slag bulk will be higher than usual; foaming will probably occur to an extent requiring a reduction in the normal fuel rates and resulting in a bath that is relatively cold at the melt.

If the hot-metal charging is delayed too long, there may be a loss of yield in addition to the loss of time, the melt carbon may be lower than desired, and in some cases extra fettling may be needed after the tap.

High fuel-input rates are essential during this period for which a time objective is given. The shop average time for starting the hot-metal charge is 115 min. after the finish of the cold charge.

Flush Slag and Melt

Close attention is paid to obtaining a satisfactory flush-off with every hot-metal charge heat. At the fixed furnaces the normal quantity of slag flushed off is one full pot, and $1\frac{1}{2}$–2 pots are run off at the tilting furnace per heat.

Flush slags vary in composition according to the conditions. A composite analysis is:

SiO_2	21·7%	MnO	14·0%
FeO	30·7%	CaO	16·0%
Fe_2O_3	4·4%	P_2O_5	2·5%

After the hot metal has been charged, the fuel rate is somewhat reduced from the maximum rate used during the charging and heating of the cold stock, and the coke-oven gas that has been used in addition to the oil fuel during the earlier stages is usually shut off.

Further reductions in the fuel rate are made as the lime rises to the surface. Early additions of bauxite are made to assist the ore additions to flux this lime into solution. Bauxite is not so powerful a flux as fluorspar (which is available for use if required), but its use is not accompanied by the foaming that is associated with the use of fluorspar, especially when the bath carbon is high. Bauxite exerts a beneficial influence on the rates of desulphurization and dephosphorization in hastening the solution of lime.

Refining and Tapping

Slag pancakes are used for the estimation of slag compositions. The routine practice is to draw two pancake samples with each metal bath sample. One sample is retained for inspection and the other is sent to the laboratory for a rapid determination of the FeO content. Samples are retained for any further analysis that may be required. Bath samples are analysed by rapid methods. A carbometer is used for quick estimates of bath carbons. An immersion pyrometer will be in service at an early date. Tapholes are opened out with oxygen lances.

Ferro-alloy ladle additions are made at the fixed furnaces *via* chutes, the weighed materials being placed in containers that have counterbalanced manually operated gates leading to the chutes. At the tilting furnace, a mechanically operated container is carried by the pit crane.

Finishing slags overflow the ladles into waiting pots. These pots, which are also used for flush slags, have a capacity of 360 cu. ft. The total amount of slag (finishing slag plus flush slag) averages 270–290 lb. per ton of steel.

The joints are broken and the tapping runners are removed at the fixed furnaces by the auxiliary hoists of the pit cranes.

Process Control

The various types of steel made on the plant are classified and coded. Standard instructions are issued for each type and class. These instructions specify the type of charge, the minimum limestone charge (for an iron of standard analysis, adjustments being made for variations from this standard), and melt

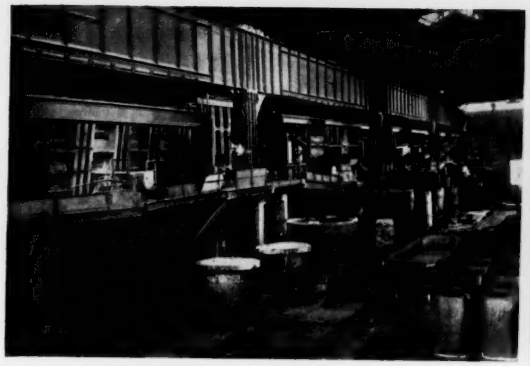


Fig. 8—General view of furnaces from tapping side ; tilting furnace in left foreground

Fig. 9—Removal of debris and slag from pocket with a mechanical shovel

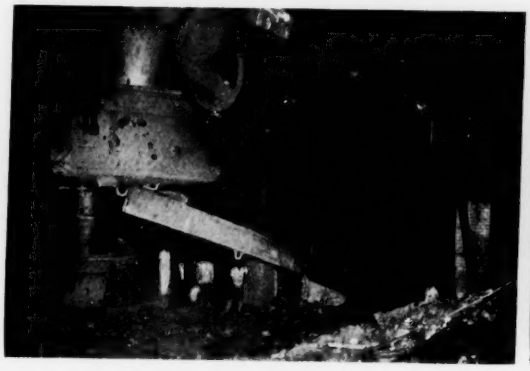


Fig. 10—Use of lever in slag pocket

Fig. 11—Clearing lower checkers

Fig. 12—Method of support of main roof centres

Fig. 13—Method of support of ramp roof centres

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V ra

carbon aims designed to allow for the use of a reasonable quantity of feed ore. Minimum *V*-ratio values of the tapping slags are specified, and late oreing is not permitted.

Trained metallurgical observers watch every stage of the manufacture of all heats and record relevant data.

Rimming Steels—The steels of this type are rolled in the continuous wide-strip mill for products that include tinplate, enamelling strip, and deep-drawing qualities.

Minimum FeO contents of the finishing slags are specified. Reboils are made with pig iron, spiegel, and, in the case of low-metalloid heats, silicon pig. Adjustments are made in the moulds with additions of granulated aluminium and occasionally with sodium fluoride. Ingots are capped with aluminium, heavy caps, or light plates after sufficient rim formation.

Semi-Killed Steels—These steels are made for sections, plates, or billets. Additions of pig iron or spiegel are used in finishing the heats; 15% silicon pig or silico-manganese additions are used for blocking purposes, according to the product. The ferro-manganese addition is made in the bath whenever the final manganese content is required to be over 0·60%. Not more than 0·03% of carbon is recarburized with ladle additions of coke.

Ladle additions include ferro-silicon (48% Si) in amounts according to a table based on the final carbon content of the bath and the FeO content of the slag. Aluminium additions in the ladle are varied according to the mould size.

Adjusting additions of aluminium are given in the moulds, three-quarters of the granulated addition being fed into the body of each ingot and the remainder into the top.

Rail Steels—Rail steels are usually made at the tilting furnace. Heats are diverted into other classes of steel whenever the melt carbon is insufficient to allow for the use of at least one full box of feed ore.

Pig iron or spiegel additions are used in finishing the heats, and a standard weight of 1925 lb. of 15% silicon pig is added before the ferro-manganese bath addition. Ladle additions of coke are limited to a maximum equivalent of 0·03% of carbon, and 48% Si ferro-silicon is used in the ladle additions.

The heats are poured into big-end-down 25 in. × 28 in. × 92 in. moulds.

Heat Logs and Finishing Slags

Representative heat logs of the more usual types of steel are given in Table IV. Examples of analyses of composite samples of finishing slags are:

	Rimming Steel	Semi-Killed Steel	Rail Steel
CaO, %	41·50	46·30	45·00
SiO_2, %	9·00	12·60	11·10
Al_2O_3, %	1·09	1·90	2·46
MnO, %	5·00	5·29	6·19
FeO, %	19·80	10·80	12·26
Fe_2O_3, %	10·47	7·51	7·15
MgO, %	10·50	12·00	12·26
P_2O_5, %	2·64	3·60	3·58
V ratio $\frac{CaO}{SiO_2}$	4·6	3·7	4·1

OUTPUTS AND CONSUMPTION OF MATERIALS

The furnace outputs during 1953 were:

	Long tons of good ingots
Furnace 1 (tilter)	107,413
,, 2 (fixed)	120,078
,, 3 (fixed)	117,387
,, 4 (fixed)	115,441
Total	460,319

The shop average consumption of materials per long ton of ingots for 1953 was:

Hot metal	1544·9 lb.
Steel scrap	649·6 ,,
Iron scrap	73·5 ,,
Cold pig	53·5 ,,
Iron ore	282·0 ,,
Limestone	116·3 ,,
Lime	1·8 ,,
Bauxite	4·7 ,,
Fluorspar	0·5 ,,
Spiegel	4·2 ,,
Ferro-manganese	15·7 ,,
Silicon pig (15% Si)	3·2 ,,
Ferro-silicon (48% Si)	2·3 ,,
Raw dolomite (screened)	89·8 ,,
Burnt dolomite	41·7 ,,
Magnesitic hearth-repair material	5·4 ,,
Chrome ore	1·6 ,,

The calorific consumption (inclusive of all heating-up) was $4·36 \times 10^6$ B.Th.U. per long ton of steel.

Some details of the best month's (December, 1953) production are:

Furnace	1	2	3	4	Shop Total
Make of good ingots, long tons	9610	12,157	12,669	10,205	44,641
Heats	52	61	64	51	
Calorific consumption, 10^6 B.Th.U. per ton of steel	4·81	3·81	3·78	4·17	

The calorific consumption includes heating-up after repairs. The repairs made during the month were:

Furnace 1: New roof and ramps, new front wall and repairs to the back wall, bulkhead replacements, uptake repairs, and the cleaning of checkers, slag pockets, and flues

Furnace 4: New main roof, new front wall, and repairs to uptakes and bulkheads.

PIT PRACTICE

Ladles

The elliptical steel-pouring ladles, enlarged from 150 to 200 metric tons capacity, have the following shell dimensions:

Top width	11 ft. 7½ in.–14 ft. 7½ in.
Bottom width	9 ft. 11½ in.–12 ft. 11½ in.
Height	12 ft. 1½ in.

The ladles are lined with a working lining of 3 in. of firebrick over a 2½-in. firebrick safety lining. The lower courses of the working lining are reinforced to give a thickness of working lining of 5 in. in this portion. The average life of a working lining is nine heats.

Table IV—HEAT LOGS

	Tilting Furnace	Fixed Furnaces	
	Rail Steel	Semi-Killed Steel	Rimming Steel
Heat No.	31366	33287	34342
Analysis Specification	C, % 0·67 –0·73 | Mn, % 0·70 –0·85 | P, % 0·030 max. | S, % 0·040 max. | Si, % 0·15 –0·20	C, % 0·16 –0·20 | Mn, % 0·45 –0·55 | P, % 0·040 max. | S, % 0·040 max. | Si, % 0·10 max.	C, % 0·08 max. | Mn, % 0·30 –0·40 | P, % 0·030 max. | S, % 0·035 max.
Charges, tons			
Steel scrap	34·80	61·96	63·48
Iron scrap	21·26	7·92	9·05
Limestone	8·00	10·77	10·14
Iron ore	21·26	19·68	22·96
Hot metal	130·14	133·50	130·58
Analysis of hot metal	Si, % 0·82 | Mn, % 1·17 | S, % 0·030	Si, % 0·86 | Mn, % 1·17 | S, % 0·028	Si, % 0·79 | Mn, % 1·12 | S, % 0·032
Times			
Finish previous tap	1.30	10.00	12.15
Start charging	2.00	10.20	12.50
Finish cold charge	2.45	11.20	13.40
Start hot metal	4.50	13.00	15.40
Finish hot metal	5.30	14.10	16.50
Finish flush slag	6.20 (2 pots)	14.35 (1 pot)	18.00 (1 pot)
Additions	Time 9.00 660 lb. bauxite 9.20 5180 lb. ore 11.17 2200 lb. spiegel 11.41 1925 lb. 15% Si pig iron 11.50 3960 lb. ferro-manganese	Time 17.30 528 lb. bauxite 18.10 396 lb. bauxite 18.25 5180 lb. ore 18.50 330 lb. bauxite 19.23 1700 lb. pig iron 19.40 1100 lb. 15% Si pig iron	Time 19.50 660 lb. bauxite 21.30 2930 lb. limestone 2590 lb. ore 22.10 3415 lb. pig iron
Bath Samples	Time | C, % | Mn, % | P, % | S, % | FeO, % 9.15 | 1·31 | 0·15 | 0·030 | 0·036 | 14·5 10.50 | 0·74 | 0·11 | 0·020 | 0·036 | 17·0 11.15 | 0·68 | 0·10 | 0·020 | 0·036 | 14·0 11.40 | 0·64 | 0·16 | 0·020 | ... | 13·0	Time | C, % | Mn, % | P, % | S, % | FeO, % 18.20 | 0·56 | 0·14 | 0·050 | 0·035 | 8·5 19.20 | 0·24 | 0·13 | 0·020 | 0·032 | 12·5	Time | C, % | Mn, % | P, % | S, % | FeO, % 20.30 | 0·54 | 0·14 | 0·040 | 0·041 | 15·0 22.09 | 0·11 | 0·10 | 0·020 | 0·034 | 19·0
Ladle Additions, lb.			
Ferro-manganese	440	2640	2640
Ferro-silicon (48% Si)	1760	528	...
Coke	317	...	...
Aluminium	...	110	...
Nozzle size, in.	2	2	2
Time			
Start tap	12.00	19.46	22.35
Finish tap	12.15	20.01	22.50
Start teem	12.21	20.04	22.53
Finish teem	13.00	20.42	23.33
Total Mould Additions, lb.			
Aluminium (granulated)	...	15·2	8
„ (capping)	...	...	208
Teem Notes			
Moulds	Warm, cleaned, treated	Warm, cleaned, treated	Warm, cleaned, treated
Remarks	Teem good; ingot tops convex	Teem good; ingot tops convex	Teem good; effervescence good, 2 in. rise; tops convex
Track Times			
Removed from pit	13.45 (45 min. holding time)	20.49	23.43
Started to strip	14.05	21.05	23.58
Pit Sample Analysis	C, % 0·69 | Mn, % 0·74 | P, % 0·014 | S, % 0·031 | Si, % 0·18	C, % 0·17 | Mn, % 0·47 | P, % 0·012 | S, % 0·030	C, % 0·08 | Mn, % 0·36 | P, % 0·008 | S, % 0·030
Ingot Size	25 in. × 28 in. × 90 in. high	23 in. × 49 in. × 71 in. high	23 in. × 49 in. × 72 in. high
Total Weight of Good Ingots, tons	182·34	200·9	201·2
Butts, Skull, etc., tons	0·49	1·97	...

Notes: All the weights given have been converted from metric to British units. The weights of the additions of ore, limestone, and cold pig are taken from the standard weight contents of boxes. The weights of bauxite are from the standard weight contents of shovels.

The composition and properties of the ladle bricks are:

SiO_2	61·30%
Al_2O_3 (inc. TiO_2)	36·80%
Fe_2O_3	1·80%
CaO	0·20%
MgO	0·05%
Apparent porosity	23·1 vol.-%
Apparent specific gravity	2·05
Cold crushing strength	250 kg./sq. cm. (3556 lb./sq. in.)
Refractoriness	1700–1720° C.
Reversible expansion (20–1000° C.)	0·49%

Stoppers

All the ladles have single stoppers; these are made up during the day turn by a stopper maker and an assistant. The 2-in. dia. stopper rods, 13 ft. 2 in. long, are covered with the usual sleeves and have imported heavy-duty graphite heads attached with pins and keys. All the stoppers are dried in a vertical gas-fired oven which holds 48 stoppers. The assemblies are suspended from a monorail so that they pass through the oven in a single file.

Nozzles

Imported fireclay nozzles are used for pouring. An analysis of nozzle material is:

SiO_2	60·87%
Al_2O_3	33·40%
Fe_2O_3	5·50%
CaO and MgO	Trace

Nozzle sizes in general use are of $1\frac{3}{4}$ in. and 2 in. orifice dia. Larger-sized nozzle orifices are reported to give good results elsewhere, but experience at Volta Redonda, after experiments with faster pouring rates, has been that moderate pouring speeds give better yields and mill results, especially when used in connection with rimming steels. All heats are top-poured.

Ingot Moulds

The following are details of the moulds in general use:

	Mould Weight, tons	Av. Wall Thickness, in.	Ingot Weight, tons
21 in. × 25 in. × 75 in. high	5·32	$5\frac{1}{2}$	4·2
25 in. × 28 in. × 75 in. high	7·09	$6\frac{1}{2}$	5·7
25 in. × 28 in. × 92 in. high	8·70	$6\frac{7}{16}$	6·9
23 in. × 37 in. × 77 in. high	8·96	$7\frac{3}{8}$	6·9
23 in. × 49 in. × 77 in. high	12·15	9	9·3

These are all wide-end-down moulds, and the weights are in long tons. Originally, all the moulds used were imported, and the consumptions were:

Mould	Weight of Mould per Long Ton of Steel, lb.
21 in. × 25 in.	26·2
25 in. × 28 in.	24·0
23 in. × 49 in.	38·3

Since the opening of the Company's foundry in 1949, all the moulds have been made on the plant. With the total production of iron from the single blast-furnace being required for the basic-iron needs of the steel furnaces, no supplies of foundry iron have been available, and moulds have been made by melting a mixture of up to 50% of used-mould scrap with the balance made up of basic iron; ferro-silicon additions were made in the ladle. Under such conditions of recycled scrap, mould life has been lowered progressively, especially in the smaller sizes, the consumptions of the types in most general use being:

	Weight of Mould per Long Ton of Steel, lb.	
	1952	1953
23 in. × 49 in.	40·7	46·8
25 in. × 28 in.	45·5	57·3

With the coming into operation in early 1954 of the second blast-furnace, and the subsequent availability of supplies of suitable iron, it is expected that improvements in mould consumption will be obtained.

Moulds are rejected, as at other plants, when cracks develop or when the mould surface is considered unsuitable for the production of the requisite quality of ingots. Careful records are kept of the life of each mould and of the reason for the final scrapping.

Mould Treatment

All the moulds are sprayed with a light tar mixture after cleaning. Track times are watched carefully. Standard maximum times are specified from the completion of teeming to the start of stripping. Sufficient cars and moulds are available, and the aim is to teem with mould temperatures of 50–100° C.

Stools

All stools are used without slurrying and without steel plates. Stools are rejected when they have depressions, measured with a gauge, in excess of 3 in.

Cleaning

Various mechanical aids are used for cleaning up the pit. A 25-ft. long steel rake is used for drawing out the hot slag from between the ladle stands of the fixed furnaces. The head of the rake is supported by a cable attached to the hook of an auxiliary hoist of a pit crane, and the body is carried on trunnions held by the ladle hooks. Solidified slag is broken up with an ingot dropped from a suspended magnet. The loosened and broken slag is picked up with a large-capacity grab bucket carried by a pit crane and loaded either directly into a large side-tipping wagon or into a large tip box of 175 cu. ft. capacity, which is lifted by its trunnions with the main ladle hooks for discharging into a wagon at a convenient moment.

Furnace Repairs

The availability of furnaces is a major consideration in production, and close attention is paid to the subject of furnace repairs. The plant policy is to schedule all furnace repairs and to work according to plan.

Sometimes, when the scheduled time for the repair of a particular furnace becomes due, it is possible to operate the furnace with safety for several more heats. Even in such a case, it is advisable to adhere to the schedule and take the furnace off. By such an arrangement it is possible to begin the repair under the most favourable conditions, *i.e.*, having a sufficient concentration of men, equipment, and materials assembled on the spot at the planned time. This method permits the planning of a reasonable continuity level of production and enables use to be made of the minimum amount of labour by the avoidance of having more than one furnace under repair at the

same time. As the repairs are planned in advance, other interested departments have an opportunity to plan suitable adjustments, also in advance.

In the general schedule the furnace repairs are arranged on the basis of each furnace requiring one top repair (main roof replacement, new front wall, and repairs where necessary to the back walls, uptakes, and bulkheads) between each partial general repair. A partial general repair is defined as a repair requiring a replacement of the ramps and main roof, the renewal or repair of linings, the removal of slag from the pockets, the repair or renewal of bulkheads, uptakes, supporting arches, fantails, and slag pockets, cleaning out the flues, and the replacement of the upper courses of checkers. A full general repair includes the replacement of one or more sets of checkers down to the rider arches. Hot patching of roofs is carried out between the scheduled main repairs, all roofs being inspected at frequent intervals.

Before each repair, the furnace is carefully surveyed and a list of the anticipated repairs is drawn up. A meeting of representatives of the masonry, maintenance, industrial engineering, and open-hearth departments is held, and any problems that are expected to arise during the execution of the particular job are discussed. An agreed work chart is prepared showing the work required from each department and the time estimate for the work. Time estimates are based on past experience and on data compiled from the time studies made by trained observers of every repair. Every care is taken to dovetail the work of the various departments. Positioning of supplies of materials and equipment and the movements of wagons are arranged. Copies of the work chart are circulated to all concerned; one copy, exhibited at the site of the repair, is used to mark off the actual progress against the estimate.

The time taken for any repair naturally depends on the amount of work required in the particular case. Top repairs have been made in as little as 26 hr. 15 min. (furnace 3, Feb., 1953) and a partial general repair in 59 hr. (furnace 1, Dec., 1953) from the time of fuel-off to the start of heating-up, but the average times (1953) are 36·35 hr. and 112·9 hr., respectively.

Furnace availability during 1953 was 92·1%, this figure being obtained by deducting from the total number of hours in the year all furnace repair time (general, top, and all hot patching) plus all heating-up time. Hot patching is included, as a furnace cannot be said to be 'available' when the fuel is off, even for a limited time. Heating-up time is the time from the start of heating-up to 3 hr. before the addition of the hot-metal portion of the charge. Heating-up after a main repair is not rushed unduly, the average times being 39·9 hr. after a partial general repair and 26·6 hr. after a top repair.

Procedure at a Partial General Repair

After the tap-out and after any hot repairs required by the hearth have been made, the fuel is shut off. The furnace reversal system is 'centred' and the waste-heat-boiler fan is kept running with the reversal dampers raised on timbers to the maximum height and the louvres set to give the maximum draught.

The doors and frames are removed, holes are made in the end bulkheads, and the roof is knocked in with the use, if necessary, of the hot-metal-crane hooks. The ram of a charging machine is used to demolish the front walls.

As one of the most time-consuming jobs can be the removal of the slag and the consequent repair of the pockets, work is started at this point, ahead of the repair, by drilling holes through the bulkheads into the solidified slag during the making of the last few heats. At the start of the repair, blast shots are fired in these holes to fracture the large masses of slag. The remains of the bulkheads are torn down by Diesel-driven mechanical shovels that remove the slag and brick refuse (Fig. 9). If any inner mass of slag remains unfractured by the blasts, it is dislodged by a large lever which is inserted into the flue beneath. The lever, 45 ft. long, is carried by a pit crane, a ladle being used to supply the weight at one end; heavy timbers are used for the fulcrum (Fig. 10).

Demolition of the checker bulkheads is started at the same time as the wrecking work on the other parts and, after the removal of the bricks from the entrances, the top courses of checker bricks are taken out, steel strips having first been pushed between the courses at the cellar level to prevent dust and brick rubbish from falling into the lower passages. When the required number of courses have been removed, the strips are withdrawn and compressed-air lances are used to clean the lower checkers (Fig. 11).

In the meantime, while the brick refuse from the roof and linings is being removed from the hearth, mechanics replace any damaged rear skewback channels. They are followed by the bricklayers, who begin work on the back lining and brick taphole arch while the mechanics move on to the work at the front skewback channels and front-wall coolers. After the backwall repairs have been completed and while work is continuing on the taphole arch from the outside, the bricklayers erect the front linings and, at the same time, work starts on the installation of the roof-centres supports and the roof centres. The supports consist of steel channels; one end of each channel rests on the sloping back wall or upon a brick pier; the other end, raised into position by a chain hoist, is held by a clamp attached to the furnace upper steelwork (Figs. 12 and 13). This method of support is erected much more quickly and is more economical than the older method, in which the support was provided by a veritable forest of timbers.

The roof having been installed and the centres and supports removed, any ramming of the upper banks, sloping back wall, or taphole that is required begins, the moistened cold-setting magnesitic ramming material being mixed in a concrete-mixer set on the charging platform. Bricklayers freed by the completion of the roof start work on the uptakes and lower arches.

After the lower checkers have been cleaned, men enter the flues to clean out the flue dirt accumulations while the bricklayers replace the upper courses of checkers. Building of the slag-pocket false walls and bulkheads, furnace ends, and checker bulkheads is carried out at the same time as the flue cleaning, with the object of finishing at the same time and completing the repair.

Large man-cooling fans are used at various points throughout the work. Ample lighting is provided from cables plugged in at permanent panels. The bricks required for the repair are loaded in advance on wooden pallets for lifting on the railway cars with lift trucks. These loaded pallets provide an easy method of brick handling on the job. Mechanical hoists elevate the flue dust in containers from the flues, the dirt being tipped directly into waiting motor trucks. These trucks also run the checker bricks into the cellar; conveyors are used where necessary. In the pit side, the debris and slag deposits are loaded into railway wagons or into motor tip-trucks by the mechanical shovels or crane-handled grab buckets.

Manning

The shop is now manned entirely by Brazilian operatives who have been trained on the plant. After a preliminary screening, applicants for positions are given a course of instruction before taking up an operating position.

Extensions and Alterations

Present work in hand includes the erection of two new O.H. furnaces, each of 200 metric tons nominal capacity, and of an additional mixer. The present mixer will be transferred later to a different site and level in an extension to the mixer building at the west side of the shop.

The new O.H. furnaces being built at the eastern extension of the shop will have generous allowances of bath area and of regenerative and slag-pocket capacity. The equipment for draughting and for the supply of combustion air will have ample reserve capacity over the expected requirements. Front-flushing arrangements will be provided.

Consideration is being given to the replacement and lengthening of the hearths of the existing fixed furnaces, and to the improvement of draughting and of air supplies at all the present furnaces. Supplies of oxygen will probably be furnished for bath decarburization.

Ultimate plans involve the addition of further capacity sufficient to give an annual total production of one million metric tons of steel.

Acknowledgments

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Use of a Thermal Model to Determine Temperature under Blast-Furnace Hearths

By E. J. Williams and E. J. Burton, B.A., A.Inst.P.

SYNOPSIS

A 1:55 scale model of the Margam No. 2 blast-furnace hearth and foundations has been constructed. The model hearth is maintained at temperatures equal to those in the actual furnace so that the temperature scale is unity, and thus the model allows for any changes in thermal properties of the furnace with temperature. This has shown that on the axis the whole of the layer of carbon bricks is above the freezing temperature of iron, and that the temperatures at the concrete/refractory-concrete interface will reach the safety limit (250° C.) if the hearth erodes and the surrounding soil is dry. The contours from the model agreed approximately with measurements made on the production furnace and with contours obtained from an electrical analogue (developed by the Ironmaking Division of B.I.S.R.A.). 983

Introduction

THE use of carbon bricks in the hearth walls of a blast-furnace has been claimed to reduce the number of breakouts.[1] The carbon bricks are neither attacked chemically nor wetted by liquid iron and slag, their refractoriness-under-load is much higher than the best fireclay bricks, and they are more resistant to abrasion. These qualities and the success of the wall linings have led to the use of carbon bricks for the hearth.[1,2,3] However, these advantages can be realized only if the liquid iron can be prevented from penetrating through the joints, because, although the bricks will withstand the iron, they may be floated away easily. Carbon has a high thermal conductivity, so that water-coolers inserted behind the bricks in the hearth walls can freeze the iron before penetration is complete. In the hearth the carbon bricks are not generally cooled and there is danger of the hearth becoming saturated in liquid iron. Furthermore, if the temperature in the underlying fireclay bricks reaches the softening or vitrification temperature, the brick may shrink and endanger the stability of the hearth; if the temperature rises to 250° C. in the concrete foundations, the

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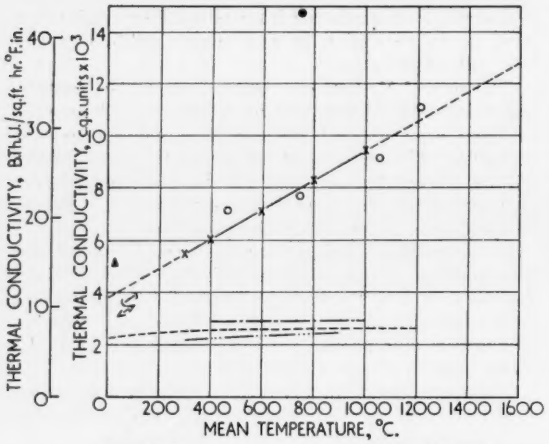
THERMAL CONDUCTIVITY, BTh.U./sq.ft. hr.°F.in.
THERMAL CONDUCTIVITY, C.g.s.units x10³
MEAN TEMPERATURE, °C.
0 200 400 600 800 1000 1200 1400 1600
Carbon brick
x Unused—Chesters, Elliot, and Mackenzie
o Unused—J.F. Clements
▲ Unused—N.P.L.
● Brick heated at 1500°C. for 8 hr.—J.F. Clements
Unfired carbon ramming
(—>Machine-made block, bulk density 95·7 lb./cu.ft.
<—>Hand-ramped block, bulk density 91·6 lb./cu.ft.
Firebrick
—·—42–44% alumina—porosity 26%, bulk density 120 lb./cu.ft.
—··—42% alumina—porosity 40%, bulk density 101 lb./cu.ft.
Refractory concrete
----3:2:1 mix

Fig. 1—Thermal conductivity of blast-furnace hearth refractories

crushing strength begins to fall,[4] the reduction being 35% at 400° C., and the whole structure may be imperilled. Obviously, if a method were available for predicting the temperatures beneath the hearth, the design could be reconsidered, if necessary, and changed to prevent any overheating, for example, by sub-hearth air cooling, as suggested by Voice.[5]

The temperatures beneath a hearth may be calculated if the temperatures at the boundaries and the thermal properties of the refractory materials are known. Keller[6] has presented an approximate analytical solution which is a useful guide for new furnaces made entirely from refractory brick. For composite and eroded hearths the problem may be solved by numerical computation using desk calculating machines, by constructing an electrical analogue of the heat flow as used by Meachen,[7] or by using the new electronic computing devices. A fourth method, described in this paper, is to construct a small scale model of the furnace foundations and measure directly the distribution of temperatures throughout the model.

THE THERMAL MODEL

The same temperature distribution will be obtained in a scale model as in the actual furnace, provided that the materials of both have the same thermal conductivity and the same thermal capacity per unit volume, that the model hearth is maintained at iron-making temperatures, and that the proportion of the perimeter water-cooled is the same in both. The temperature distribution at any time during the heating process may be obtained from the thermal model, although the time taken to heat the model hearth itself introduces some uncertainty in the origin of the time scale. The electrical analogue* gives the distribution only at the steady state, whereas the more elaborate electronic computing machines are capable of giving the distribution at any time. Both electrical methods assume the thermal properties of the materials.

Westbrook[9] has used a thermal model with a carbon hearth maintained at only the temperature of boiling water, and claims that the effect of temperature on thermal conductivity was negligible. His claim was based on the similarity between the contours obtained from two models differing in the thermal conductivity of the carbon from 8 units to 3 units. His contours show a sharp increase in temperature on the axis, suggesting a leak of water there. Furthermore, the increase in conductivity of carbon up to iron-making temperatures is greater than three times. The available data on the variation with temperature of the thermal conductivity of blast-furnace refractories have been collected together in the Appendix and are presented in Fig. 1.

In the experiments described in the paper, the model was made from the same materials as a production furnace (the No. 2 furnace at the Margam works of the Steel Company of Wales Ltd.), and the model hearth was maintained at iron-making temperatures. This furnace was chosen because it was equipped with thermocouples in the lower section of the foundation, thus affording a means of checking the model results. The parallel investigation by Meachen and Jennings[10] with the electrical analogue enabled changes of design to be investigated rapidly once it was proved that results from the two models agreed with one another and with actual practice.

Construction of the Model

In the model the dimensions of the furnace were reduced to approximately 1/55th. This scale factor was chosen for two reasons: firstly, it gave a model diameter of a suitable size (about 7 in.), and secondly, in a laboratory experiment of 8 hr. the same temperature distribution was obtained as that in the industrial

* Liebmann[8] has suggested how this limitation may be overcome.

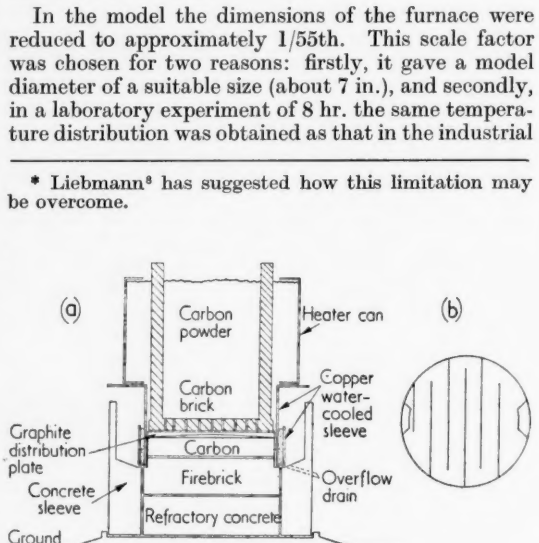

Fig. 2—(*a*) Cross-section of thermal model; (*b*) plan view of graphite heater

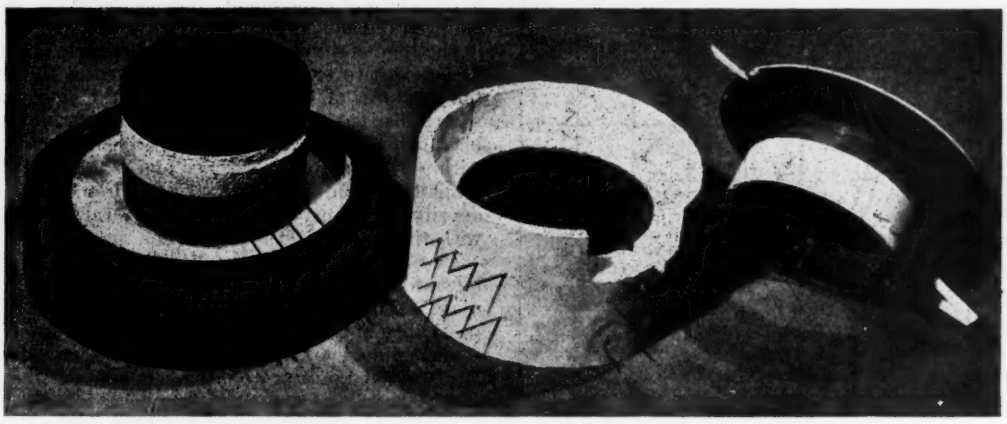

Fig. 3—Components of thermal model

furnace operating for 2·5 years, because the time to reach any given temperature distribution is reduced in the model by the square of the scale factor.

A cross-section of the model is shown in Fig. 2. The hearth was represented by a single disc of carbon, 6·93 in. × 0·95 in. thick, cut from an unused furnace block. The firebrick section was represented by a disc of firebrick (42% Al_2O_3, porosity 11·2%), 6·93 in. dia. × 2·82 in. thick. The refractory concrete was made from a disc cast with a mixture of six parts of refractory concrete to one of crushed firebrick. The concrete base, 13·8 in. dia. × 3·0 in. thick, and the concrete sleeve were made from castings using cement and sand in the proportions of 3 : 1. The components of the model are shown in Fig. 3.

The cooling staves were simulated by a copper sleeve cooled by water streaming across its surface through a 0·005-in. gap between the sleeve and a ring main soldered to a flange at the top of the sleeve. A steel canister of 2 ft. dia. was used to contain the sand representing the soil in which the furnace is built. High resistance to heat flow at the interfaces was prevented by smearing a thin slurry of the appropriate cement across the refractory surfaces and then lapping them together.

The hearth was maintained at iron-making temperatures by a graphite grid, heated electrically. The grid, hewn from a solid cylinder of graphite, consisted of a slotted disc with two legs on a diameter acting as current leads, as shown in Fig. 2. The assembled model is shown in Fig. 4. The power to heat the model was supplied by a 24-kVA. transformer, in which the secondary voltage could be continuously varied from 0 to 16 V. This enabled any hearth temperature to be attained up to 1600° C. using 8 kW., 500 amp. at 16 V. It was difficult to maintain the temperature of the model hearth uniform because the reduction in scale increased the temperature gradients 55 times. Therefore the resistance of the heater was made greater at its perimeter to increase the heat dissipation there, and a graphite disc was interposed between the heater and the hearth. The disc served to even out any differences in temperature across the heater and to reduce the gradient across the hearth. A zone of uniform temperature about 5 in. dia. was obtained; this corresponded to a dia. of about 23 ft. on the full size and was slightly less than the real hearth dia. of 25 ft. 9 in.

The temperatures in the model were measured by thermocouples. The couple measuring the hearth temperature was made from Pt/Pt–Rh(13%) wire protected from contamination by the carbon by

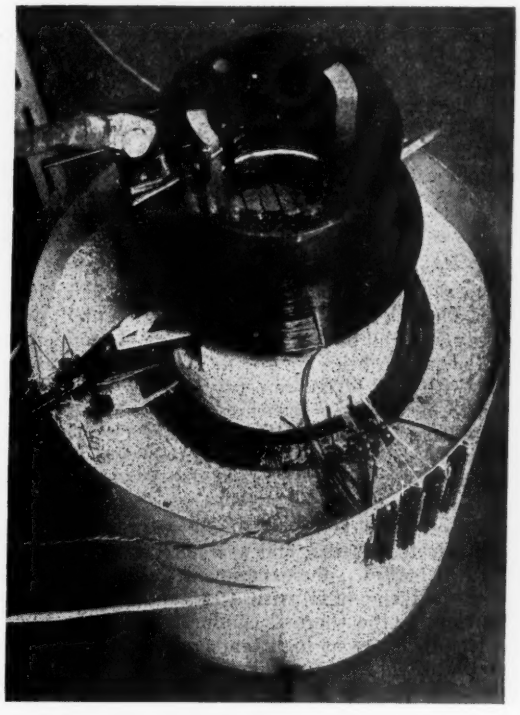

Fig. 4—Assembly of model

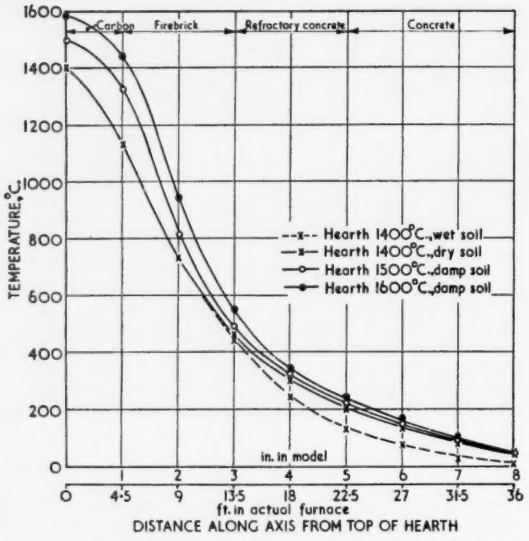

Fig. 5—Temperature distribution along hearth and foundations with hearth temperatures of 1400°, 1500°, and 1600°C.

twin-bore insulators and inserted through an inclined radial hole so that its junction was at the top surface of the hearth. The hole was filled with a slurry of alumina. The remaining 19 thermocouples were made of 28 S.W.G. chromel/alumel wire: the two couples stretched across the interface between the carbon and the firebrick were protected from the carbon by single-bore silica sheathing. The remaining couples were cemented in position. The leads from the thermocouples were taken to a central panel, from which any six could be connected to a six-point potentiometric recorder. The e.m.f. from the hearth couple was measured on a manual potentiometer.

EXPERIMENTAL DETAILS

An investigation was made of the effect on the temperature distribution throughout the foundations of the hearth temperature, of the water content of the sandy soil, and of the change in thermal conductivity of the carbon brick by graphitization and impregnation with iron. The temperature of the blast-furnace hearth has not been measured directly and estimates have varied between 1400° and 1600° C. Therefore, it was decided to carry out experiments at hearth temperatures of 1400°, 1500°, and 1600° C. The water content of the soil, the presence of underground rivers, etc., will modify the temperatures through the concrete foundation, and therefore, with the hearth kept at 1400° C., one experiment was made with dry sand and the next with wet sand. As discussed previously, the thermal conductivity of the carbon bricks increases at high temperatures as the carbon graphitizes. Also, iron impregnates the brick and the net thermal conductivity increases. The first set of experiments, outlined above, were made with carbon discs cut from an unused block. In the 8 hr. for one experiment, the conductivity of the material did not appear to increase and give a drift in the temperatures at the carbon/firebrick interface. The next two experiments carried out with hearth temperatures of 1400° and then 1500° C. were made with a disc cut from a block taken from a blown-out blast-furnace. The final two experiments were made with a disc cut from a furnace block which was both graphitized and impregnated with iron. The bulk density of this material was 125 lb./cu. ft., compared with the value of 90 lb./cu. ft. for the unused brick.

In each experiment the hearth temperature was increased at a rate of about 15° C./min. to its maximum. This slow rate of heating reduced the possibility of the hearth cracking or of the interfacial cement films breaking up under the thermal stresses. In two experiments the temperature on the axis of the hearth at the carbon/firebrick interface just exceeded the melting point of the chromel/alumel thermocouple. These temperatures were therefore estimated from the heating curve and the temperature contours through the model.

DISCUSSION OF RESULTS

Effect of Water Content of Soil

The temperature distributions along the axis for a 1400° C. hearth temperature with the foundations surrounded by wet and dry soil are shown in Fig. 5. Below the middle of the firebrick the temperatures are lowered appreciably by wet soil. The point at which the temperature exceeds 250° C. is raised from 2 ft. 3 in. to 4 ft. 6 in. above the concrete/refractory-concrete interface, and thus the water content of the soil may play an important role in preventing overheating.

Effect of Hearth Temperature

The temperature distributions along the axis for

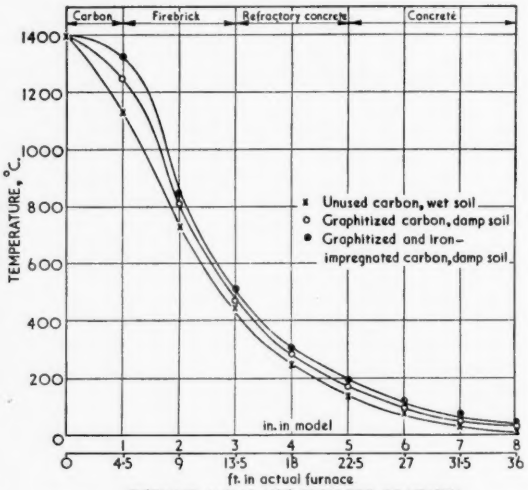

Fig. 6—Temperature distribution along axis of hearth and foundations with unused and used carbon bricks with hearth temperature of 1400°C.

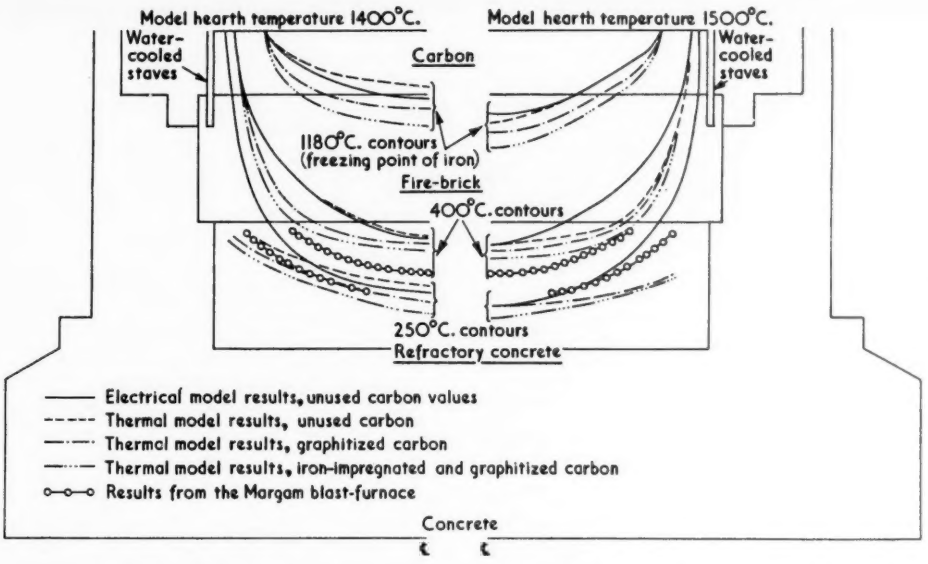

Fig. 7—Temperatures beneath Margam No. 2 furnace compared with those of the thermal model and the electrical analogue

hearth temperatures of 1400°, 1500°, and 1600° C. are shown in Fig. 5. As the hearth temperature increases, the position at which iron freezes (about 1180° C.) is lowered from 4 ft. to 5 ft. 7 in., and finally to 7 ft. 2 in. beneath the hearth. In practice, therefore, at the axis the whole of the carbon will be above the freezing temperature of the iron. The temperature at the concrete/refractory-concrete interface is less affected, but the position of the 250° C. contour is lowered from 2 ft. 3 in. at 1400° C. to 10 in. at 1600° C. above the interface.

Effect of Used Carbon Bricks

The temperature distributions along the axis for unused and used carbon bricks with a hearth temperature of 1400° C. are shown in Fig. 6. The position of the frozen-iron contour is lowered from 4 ft. to 5 ft. 6 in. when the carbon becomes graphitized, and to 6 ft. 8 in. beneath the hearth when the graphitized carbon becomes impregnated with iron. The position of the 250° C. contour is lowered from 4 ft. 6 in. to 3 ft. 5 in. for the graphitized carbon, and to 2 ft. 6 in. for the iron-impregnated carbon above the concrete/refractory-concrete interface.

COMPARISON OF MARGAM FURNACE WITH THERMAL MODEL AND ELECTRICAL ANALOGUE

The contour of freezing iron (1180° C.), the 400° C. contour, and the 250° C. contour as determined by the thermal model with hearth temperatures of 1400° and 1500° C. are shown in Fig. 7. The same contours have then been added from results obtained from the electrical analogue[11] using the thermal conductivity values for unused carbon bricks shown in Fig. 1. On the axis, the positions of the contours agree within about 3 in., except for the 1180° C., where the thermal model gives the freezing point 9 in. higher than the electrical analogue at 1400° C. and 9 in. lower at 1500° C. This is probably due to the uncertain value of the thermal conductivity of the carbon. Off the axis, the low-temperature contours in the thermal model diverge from those of the electrical analogue. This is partly due to the fact that in the thermal model the surface of the concrete surround probably reached a higher temperature than was assumed in the analogue. The effect of the changed conductivity of the used carbon may be simulated on the analogue. Meachen[11] has shown that the freezing contours obtained by both methods are brought into approximate agreement if the conductivity of the iron-impregnated carbon is taken to be about 100 B.Th.U. above 1200° C. and 130 B.Th.U. above 1400° C. Therefore, allowing a margin for safety, in any calculations the conductivity should be taken as about four times the value for the unused material, although it should be remembered that the model technique is an inaccurate method of measuring conductivity.

At Margam the temperatures across the furnace foundations have been measured with chromel/alumel thermocouples at three levels in the refractory concrete. This enabled the 400° and 250° C. contours to be determined as shown in Fig. 7. The 400° C. contour lies beneath those of both models. This suggests* that the carbon hearth has been not only impregnated with iron but also eroded, thus displacing the temperature contours downwards. The depth of the erosion is difficult to estimate from the measurements because the thermal resistance of the carbon layer, especially when graphitized, is small

*Subsequent investigation at Margam has confirmed this.

and its effect on the temperatures in the firebricks is correspondingly small. Also, it is not possible to separate erosion from a reduction in the thermal resistance of the firebrick due to vitrification under the pressure of the burden, nor is it possible to estimate the effect of thermal resistance at the interfacial boundaries. The actual 250° C. contour lies approximately along the contour obtained from the thermal model using graphitized carbon brick at a hearth temperature of 1400° C. Thus, an attempt to fit the 400° C. contour by a reduction in the thermal resistance of the hearth refractories will tend to depress the calculated 250° C. contour beneath the measured value. The best fit would be obtained if the hearth temperature were between 1450° and 1500° C., if the hearth were eroded, and if the soil around the concrete foundation were saturated with water.

A comparison between measurements on a number of blast-furnaces and predicted values from the electrical analogue has been made by Meachen and Jennings.[10] They found that the values were in reasonable agreement, the greatest discrepancy being shown by the Margam No. 2 furnace. The use of the higher value for the thermal conductivity of used carbon bricks improves the fit for the Margam furnace, and thus it may be concluded that the thermal model provides a reliable method of investigating sub-hearth temperatures.

CONCLUSIONS

(1) The comparison of the contours from the thermal model with the measured contours has shown reasonable agreement.

(2) The investigation has shown that, in the Margam No. 2 furnace,

(i) The whole of the carbon on the axis is above the freezing temperatures of iron; thus there is a considerable risk that the hearth may be floated away

(ii) The temperature at the concrete/refractory-concrete interface will reach the safety limit (250° C.) if the hearth temperature reaches 1500° C. and the hearth erodes; the depth of refractory concrete should be increased by at least 2 ft. to reduce the danger of overheating.

(3) The comparison of the contours from the thermal model with those from the electrical model has shown satisfactory agreement. The electrical analogue is particularly valuable for investigating the effect of changes of design on the temperature distribution.

(4) The increase in the thermal conductivity of carbon by graphitization and iron impregnation during use depresses the freezing contour by about 2·5 ft. on the axis. Account must therefore be taken of this increase in calculating the temperature distribution or in the use of an electrical analogue. Until reliable measurements of the thermal conductivity are available it is recommended that a value four times that of unused material be taken. This should allow a margin for safety.

Acknowledgments

The authors wish to thank the Steel Company of Wales Ltd. for providing furnace drawings and for permission to use the temperature contours from Margam No. 2 blast-furnace. They also wish to thank the Morgan Crucible Co., Ltd., for supplying the carbon bricks, and G. Stein and Co., Ltd., for supplying the firebricks. The use of a thermal analogue was suggested by Mr. M. W. Thring, now Professor of Fuel Technology in the University of Sheffield.

APPENDIX

Thermal Conductivity of Blast-Furnace Refractories

The available data for the thermal conductivity of blast-furnace refractories have been collected to determine whether the effect of temperature could be neglected. The results are presented in Fig. 1.

The thermal conductivity of carbon bricks is difficult to determine at high temperatures and there are no data available over the range of iron-making temperatures (1200–1600° C.). Chesters, Elliott, and Mackenzie[1] reported a linear increase of thermal conductivity with temperature, increasing from 15·9 B.Th.U./sq.ft. hr. ° F. in. at 300° C. to 27·2 at 1000° C., but these results cannot be extrapolated to higher temperatures. Clements[12] heated a carbon brick at 1500° C. for 8 hr., and its thermal conductivity measured at a mean temperature of 750° C. increased from 22·2 to 43·0 during that time. This was due to the graphitization of the carbon at high temperatures, and thus the conductivity of a carbon hearth after a long period of operation might have any value up to that of graphite.

The two curves for the unused firebricks, taken from data supplied by Clements,[12] show that the conductivity lies between 6·4 and 8·4. The thermal conductivity of refractory concrete given by the makers[13] over the temperature range 40–1140° C. varies from 6·6 to 7·5. The value for concrete is about 10·0, whilst carbon ramming, used to make good thermal contact between the water-cooled staves and the refractories of the hearth, also has a value of about 10·0.

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Determination of Residual Stresses in Lightly Rolled Thin Strip

By B. B. Hundy, B.Sc., Ph.D., A.I.M.

SYNOPSIS

A method of determining unidirectional residual stresses in thin steel samples is described in detail, and the accuracy and reproducibility of the method are discussed. The method is used to determine the residual stresses in lightly rolled thin steel strip. Except for very light reductions, the residual stresses increase in magnitude as the reduction is increased (up to 6% reduction). A few tests on lightly rolled copper strip, however, revealed rather different residual-stress distributions, and it is apparent that the magnitude of the residual stresses arising from rolling depends on the material being rolled as well as on the rolling conditions. 1009

MACROSCOPIC residual stresses may be induced in a metal body by non-uniform heating or cooling, by phase transformations in the metal, and by most metal-working processes. Usually the formation of residual stresses is due to inhomogeneous plastic deformation occurring during the particular treatment, arising from changes in either volume or shape. These stresses can have important effects, both beneficial and detrimental, on the behaviour of bodies containing them. For example, it has been shown that large residual stresses can play a very useful part in preventing the appearance of stretcher strains on pressings made from temper-rolled steel sheet[1] and surface compressive stresses can increase the bending fatigue life of a component.[2] On the other hand, such troubles as season cracking[3] or fire cracking[4] in wrought products are usually caused by residual stresses. It is therefore most important that the factors which affect the magnitude and distribution of the residual stresses induced by various processes and the means of controlling these by adjusting the details of the process should be known. To do this, it is necessary to measure the residual stresses in a body fairly accurately. Much work has been done on this subject and excellent reviews have been made,[5,6] which give examples of the manifold effects of residual stresses. This paper is concerned only with the measurement of residual stresses in flat products, where the stresses vary through the thickness of the product but not in its plane, and in particular with the determination of unidirectional stresses in thin mild-steel strip.

THEORY OF DETERMINATION OF RESIDUAL STRESSES IN A FLAT SPECIMEN

Residual stresses in the surface of a body can often be detected by X-ray methods[7] or by an analysis of stress coat patterns,[8] but these methods are not satisfactory for determining the distribution of the residual stresses throughout a metal body: this is usually done by removing sections of the metal and observing the deformation resulting from this unbalancing of the residual-stress equilibrium. This method can be applied to cylindrical as well as flat specimens, and it is even possible to determine triaxial residual-stress distributions in this way, although the present paper is concerned only with unidirectional stresses in a flat body.

In a flat specimen, not under any external constraints, the internal stresses are self-balancing; there are no resultant forces or moments acting on any cross-section through the specimen. If a layer of metal is removed from one face of such a specimen, some part of the stress distribution will also be removed; the stresses are then no longer balanced and external restraints must be applied to the specimen to prevent it from deforming. If the restraints are removed, the specimen deforms so as to restore the internal equilibrium, and generally the specimen changes in length and bends. If the thickness of the removed layer and of the specimen are known, and the curvature arising from the unbalancing of the stress equilibrium is measured, simple elasticity theory may be applied and the stress that was present in the removed layer may be calculated. By removing further layers and measuring the change in curvature, it is possible to determine the whole residual-stress distribution in the original specimen.

This method of measurement can be applied to flat specimens of any size, but, in practice, the experimental techniques of removing surface layers and measuring the changes in thickness and curvature have to be adjusted to suit the size of the specimen. Most previous work has been concerned with stresses in fairly thick specimens, and in such cases the experimental techniques are relatively simple; fairly thick layers can be removed and it is only necessary to take moderate precautions during this removal. Any stresses that are introduced into the specimen by the removal of the surface layers will be confined to a relatively thin layer and will not affect the results appreciably. Thus, the layers can be removed from specimens thicker than 0·2 in. by sawing,[9]

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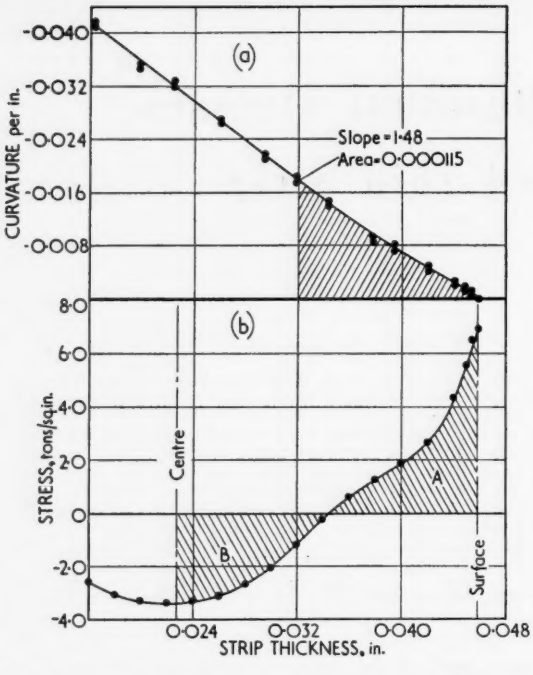


Fig. 1—Determination of the residual-stress distribution in rolled sheet by the Treuting–Read analysis: (*a*) Variation of curvature as the strip thickness is reduced by etching away one side; (*b*) residual-stress distribution

milling,[10] filing, or grinding.[11] If the specimen is smaller, thinner layers must be removed, and it is essential to ensure that no stresses are induced in the specimen during layer removal; if they are, they should be so small as to be negligible. Most mechanical methods of layer removal do not meet this requirement, and so it is necessary to use other means.

There are a number of theories for this method of stress analysis, the best known being those due to Dawidenkow,[12] Sachs and Espey,[13] and Richards[10]; these are slightly different in form but are derived in an essentially similar manner. The relation between residual stress and curvature will not be derived in the present paper, but will only be stated in its final form.

If thin uniform layers are removed from one side of a strip specimen, originally t_0 in. thick, so that the thickness is reduced to t in., the magnitude of the residual stress S at this thickness is given by:

$$S = \frac{Et^2}{6} \cdot \frac{dC}{dt} + \frac{EtC}{2} - \frac{1}{t}\int_t^{t_0} S dt \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

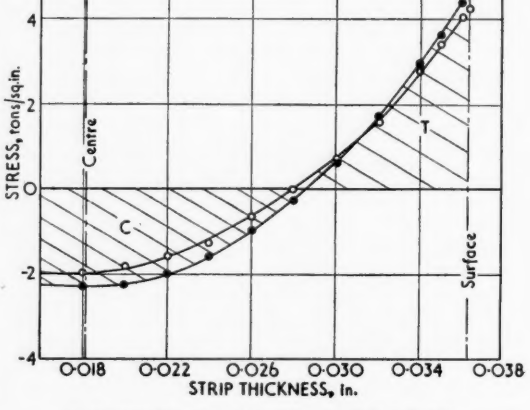
where E is the modulus of elasticity of the material and C is the curvature of the specimen when the thickness has been reduced to t. The curvature is taken to be positive when the specimen becomes concave with regard to the surface of removal of metal. It is also assumed that the specimen was originally flat; if this was not so, the original curvature must be subtracted from the subsequent values. A tensile residual stress is taken to be positive.

By plotting the curvature C against the specimen thickness t, it is possible to find the slope of the curve dC/dt, and hence to determine the first two terms in the equation. The third term, however, involves a determination of the stress and can only be found by successive approximations. A solution which overcomes this difficulty has been put forward recently by Treuting and Read.[14] Their relation, expressed in the same terms as equation (1), is:

$$S = \frac{E}{6\,(1-\nu^2)} \left[t^2 \cdot \frac{dC}{dt} + 4tC - 2\int_t^{t_0} C dt \right] \quad \ldots (2)$$

where ν is Poisson's ratio for the material. Their method of approach was rather different from that of the earlier workers, in that they took account of biaxial residual stress in their analysis.

The method of calculating the residual-stress distribution from equation (2) is rather simpler than from equation (1) and is illustrated in Fig. 1. A fair curve is drawn through the experimental thickness and curvature points (Fig. 1*a*), and convenient points on this curve are selected for calculation. The slope of the curve at a point and the area under the curve up to this point can be determined graphically and can be inserted in equation (2) to give the residual stress at this point. If the strip specimen was initially flat, it can be assumed that the stress distribution is symmetrical about the mid-point, and only half the residual-stress curve need be found (Fig. 1*b*). A check on the computed stress distribution is obtained by integrating the stress over the half thickness; by the condition of zero force this should vanish: *i.e.*, area A in Fig. 1*b* should be equal to area B. Owing to the rather easier calculations involved, equation (2) was used throughout the present work in preference to equation (1), although both equations give very similar stress distributions. Figure 2



● Treuting–Read analysis[14] ○ Sachs–Espey analysis[13]

Fig. 2—Residual-stress distributions obtained from analysis of the same data by different theories

shows the stress distributions obtained when the same data were used in the two different equations.

EXPERIMENTAL TECHNIQUE

The main experimental difficulty in carrying out a stress analysis as described in the preceding section is the removal of thin uniform layers from one side of the strip without introducing any extraneous residual stresses. These layers can be removed mechanically from thick specimens without introducing too much error, but experiments carried out on 0·050-in. thick strips of mild steel showed that even very careful milling introduced stresses which completely masked the original residual-stress distribution. Treuting and Read[14] have described a satisfactory method (grinding on emery papers followed by etching) that can be applied to very thin strip, but this method is extremely tedious and was not thought to be suitable as a regular procedure. Demorest and Leeser[15] have used an electropolishing method for removing layers from thin copper strip (0·030 in. thick), and this is apparently very satisfactory in this particular case; it minimized any relaxation effect and hydrogen pick-up. Electropolishing a reasonably sized steel specimen, however, would be more difficult and would require large currents, which are not always available. A method of chemical etching was adopted for the present work and was found to be generally satisfactory.

One face and the sides of the strip specimens were covered with a protective layer of wax and the other face was thoroughly degreased with trichlorethylene so as to promote even etching. Etching was carried out in 10% nitric acid at room temperature. The specimens were supported, with the bare face upwards, on a stainless-steel frame about $\frac{1}{2}$ in. below the surface of the acid. It was found necessary to brush the surface of the specimens continually; if this was not done, a dark film built up on the surface, giving rise to non-uniform etching. A 1-in. bristle paint brush was found to be suitable for this purpose. The acid bath quickly became exhausted and had to be renewed frequently to keep up a reasonable rate of attack (0·01 in./hr.). A faster rate of attack and slightly better surface finish could be attained by using the acid at 100° F. (38° C.), but care had to be taken to ensure that the bath did not exceed this temperature, lest the protective wax should melt at local heat spots on the specimen. Layer removal was usually carried out at room temperature.

An annealed strip, which should contain no residual stresses, was etched in this way and the variation of curvature as the thickness decreased is shown in Fig. 3. There is a slight increase in curvature, suggesting that the etching gives rise to a small tensile stress in the specimen surface. This could lead to a maximum error in the calculated residual-stress distribution of about 0·25 tons/sq. in., and it is thought that this is not significant in most cases. If a very accurate stress determination is required, an empirical correction could be made to the measured curvature. This slight error due to acid pickling might be eliminated by electrolytic etching or polishing but, as pointed out, a very high current would be needed, which would not usually be practicable.

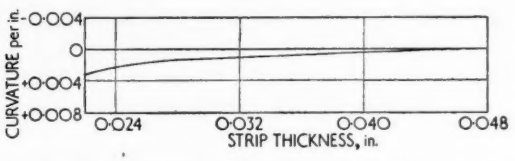


Fig. 3—Variation in curvature during the etching of an annealed mild-steel strip

The rest of the experimental technique was as follows. The specimens were 6 in. long × 1 in. wide and were sheared with a treadle guillotine from wider sheet. Experiments showed that the sheared edge did not introduce any measurable error but, to eliminate any possible trouble, the edges were carefully filed square after shearing. The specimens were then cleaned in trichlorethylene before being coated with a commercial stopping-off wax. This could be applied in two ways—either by dipping into molten wax at about 200° F. (93° C.) or by dipping in a saturated solution of the wax in trichlorethylene. The face to be etched was stopped off with adhesive cellulose tape before being coated with wax and was cleaned with trichlorethylene before being etched. Coated specimens were allowed to dry for a few days at room temperature and it was found that the wax was then hard enough to enable accurate measurements of the specimen thickness to be made without removing the wax. A convenient wax-coating thickness was 0·002–0·003 in., and measurements on etched specimens before and after removing the wax layer showed that a coat of this thickness did not affect the degree of curvature of specimens as thin as 0·012 in.

The thickness of the specimens was measured in at least four different places (*a*) before coating with wax, (*b*) after waxing and drying, and (*c*) after each layer removal. Measurements were made using a hand micrometer with a vernier scale reading to 0·0001 in. If one person made the measurements, the readings were fairly consistent, with an accuracy of about ± 0·0001 in. At the start of a determination, layers of about 0·0005–0·001 in. thick were removed from the metal specimen, and at later stages in the determination the thickness of the removed layers was increased to 0·003–0·005 in.

The curvature of a specimen was determined by measuring the sagitta of a chord of known length. The specimen was supported on edge by gripping in a jig at one end and measurements were made on a travelling microscope reading to 0·0004 in. The chord over which the measurements were taken was standardized at 3 in. This measuring technique avoids any errors due to the specimen's weight or to any forces that might arise if a mechanical measuring system were used. The curvature was measured at least twice, and more often if good agreement was not obtained at first; the agreement was usually better than 0·006 per in. Greater accuracy of curvature measurement could probably be obtained by the use of resistance strain gauges or by interferometry.[16] The use of strain gauges, however,

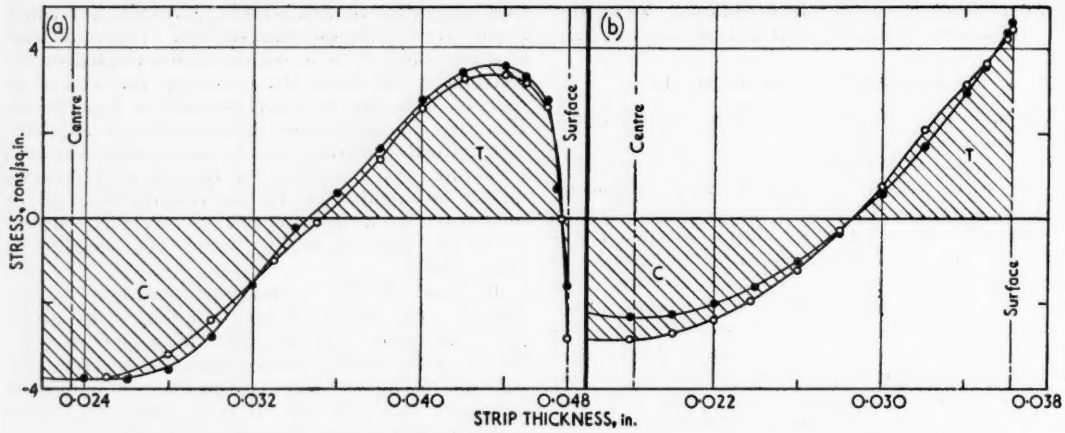


Fig. 4—Residual-stress distributions in two samples taken from the same strip

requires very great care to avoid errors due to zero shift and temperature fluctuations, and the interferometric method was thought to be too tedious for general application. For most purposes a travelling microscope gives curvature values which are sufficiently accurate.

Specimens were usually only etched to about one-third of the original thickness, since, if the specimen is initially straight, the stresses can be assumed to be symmetrical about the mid-plane, and so only half the distribution need be determined.

ACCURACY OF MEASUREMENT AND REPRODUCIBILITY OF EXPERIMENTAL RESULTS

The accuracy of measurement quoted in the previous section suggests that the calculated residual stresses in steel are probably correct to $\pm 0{\cdot}4$ tons/sq. in. This figure, however, does not apply if there are high residual stresses in a very thin surface layer; in this case the accuracy is probably much lower. The calculated residual stress in the initial stages of the analysis depends primarily on dC/dt, the slope of the curvature/thickness curve, and the inevitable slight variations in measurement make it difficult to determine this slope with a high degree of accuracy if it is changing rapidly. It is estimated that the surface stress in such a case may be incorrect by as much as 4 tons/sq. in. However, this only applies if the stress changes very rapidly in the extreme outer layers; normally it changes fairly gradually (*i.e.*, less than 2 tons/sq. in. per 0·001 in.) and can be calculated to the accuracy suggested.

The reproducibility of the method was checked by testing a number of specimens taken from adjacent points in mild-steel sheets containing unidirectional stresses. Good agreement was obtained in every case, and two typical examples are shown in Figs. 4*a* and *b*.

Demorest and Leeser[15] have suggested that relaxation of the residual stresses may occur by creep, giving rise to errors in measurement and lack of reproducibility. It is difficult to see how this could occur at low temperatures in mild steel, and X-ray tests suggest that there is no marked recovery in mild steel up to about 200° C.[17] If any relaxation did occur at room temperature, there should be a slight change in curvature if an etched specimen was kept for a few days; spot checks of this sort revealed no measurable change. In addition, other checks showed that boiling in water for a number of hours after cutting the specimen from rolled sheet had little or no effect on the residual-stress distribution. This suggests that ageing, even at this temperature, does not affect the residual stresses, and that heating during the coating with wax or during etching would not affect the results.

EXPERIMENTAL RESULTS

A check was made to see if the residual stresses due to rolling were actually unidirectional, as expected. A steel sheet was rolled to a reduction of 1·5% and specimens for analysis were cut in the rolling and transverse directions. The change in curvature as material was etched away from one face was measured and the results are shown in Fig. 5. There was little change in curvature of the specimen cut in the transverse direction, and this indicated that the

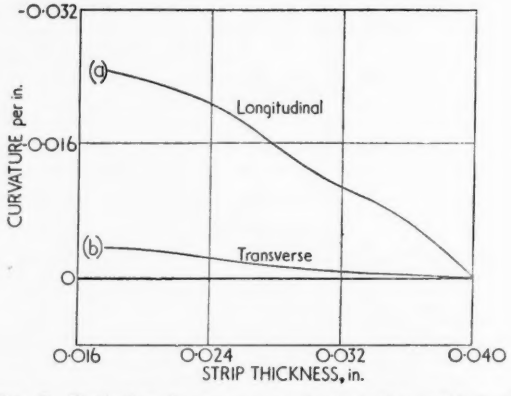
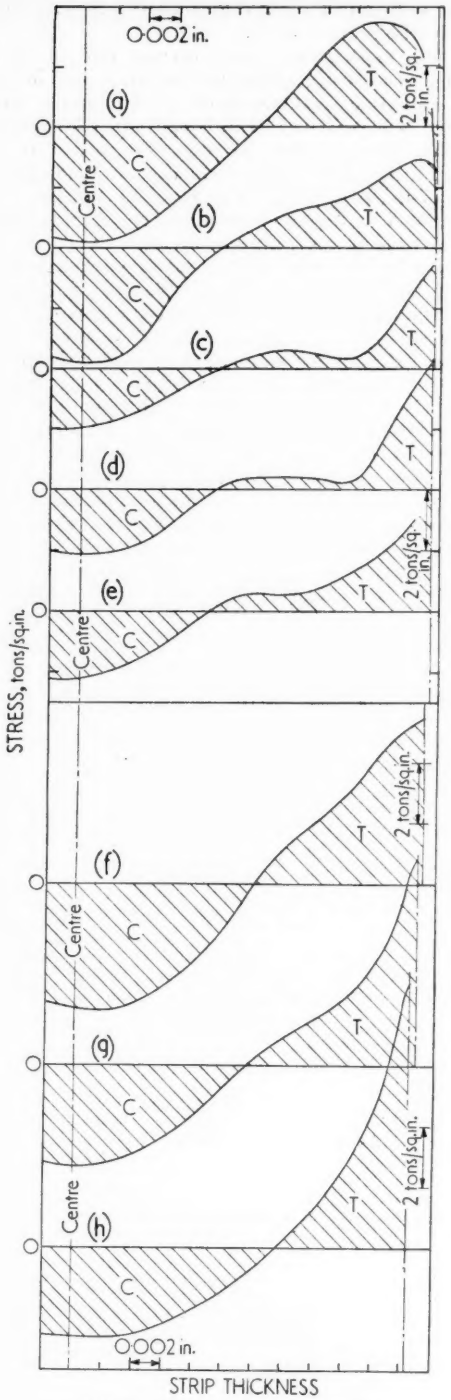


Fig. 5—Variation in curvature during the etching of mild-steel strip rolled 1·2% reduction; samples cut in (*a*) rolling direction, (*b*) transverse direction



(*a*) 0·7% reduction (*e*) 2·2% reduction
(*b*) 1·2% „ (*f*) 3·0% „
(*c*) 1·6% „ (*g*) 4·0% „
(*d*) 1·9% „ (*h*) 6·2% „

Fig. 6—Residual-stress distributions in rolled mild-steel strip

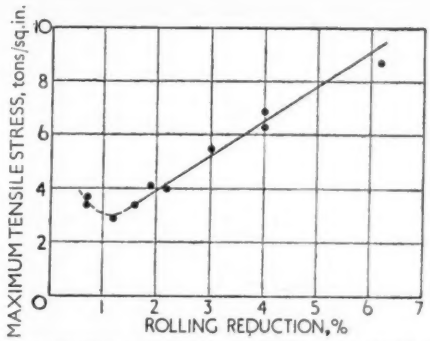


Fig. 7—Variation of maximum tensile residual stress with rolling reduction

residual stresses due to rolling are essentially unidirectional.

Other 18-S.W.G. mild-steel strips of extra-deep-drawing quality (C, 0·056%; Mn, 0·30%; S, 0·032%; P, 0·016%; Sn, 0·037%; Cu, 0·16%; Ni, 0·07%; N, 0·0044%) were rolled in single passes with various light reductions of up to 6%, at 50 ft./min. on a 10 in. × 10 in. rolling mill using dry rolls. Specimens 6 in. × 1 in. were sheared from these rolled strips at points where the strip was essentially flat, and the residual-stress distributions were determined as described in an earlier section. The results of these determinations are shown in Fig. 6. It will be noticed that the curves are not always symmetrical about the mid-point of the strip. This may be because the measured quantities tend to become more inaccurate as the strip is thinned appreciably, or because the torque is not shared equally by the two rolls (it is known that this can give rise to asymmetric variations of strain through the sheet thickness). If the residual-stress distribution across the whole section were needed, it would be necessary to take two specimens from the sheet and then carry out the layer removal on opposite sides.

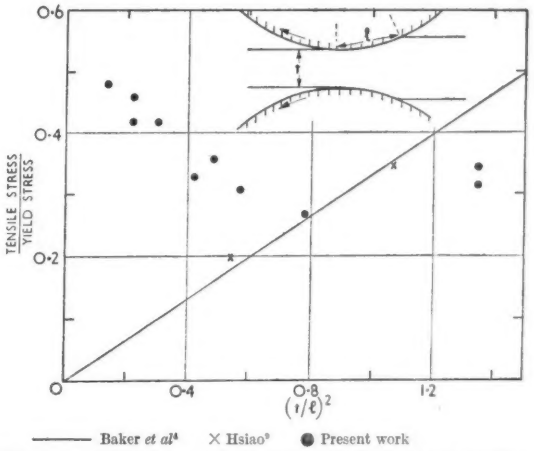
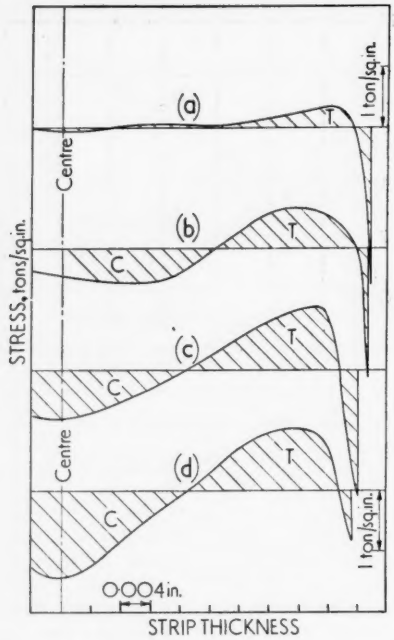


Fig. 8—Variation of maximum tensile residual stress (expressed non-dimensionally) with the rolling geometry



(*a*) 0·5% reduction (*c*) 2·6% reduction
(*b*) 1·0% „ (*d*) 5·5% „

Fig. 9—Residual-stress distributions in rolled copper strip

There is a tendency (except for the extremely light reductions) for the overall magnitude of the residual stresses to increase with the reduction. Figure 7 shows the maximum tensile stress plotted against reduction. With the exception of the strip reduced only 0·7%, the experimental points lie reasonably on a straight line. This increase of residual stress with reduction is not in agreement with the work of Baker, Ricksecker, and Baldwin[4] or Hsiao,[9] who found that the residual tensile stress decreased as the reduction was increased. Baker *et al.* also found, by plotting the results non-dimensionally, that the residual stress was directly proportional to $(t/l)^2$, where t is the exit thickness of the specimen and l is the length of the arc of contact between the specimen and the rolls. The tensile yield stress was measured on the rolled specimens used in the present investigation, and in Fig. 8 the maximum tensile residual stress, expressed as a proportion of the yield stress, is plotted against $(t/l)^2$. By expressing the residual stresses in this non-dimensional manner, it should be possible to compare these results with those of other workers using different metals, and the relation suggested by Baker *et al.* is therefore shown in this diagram, together with Hsiao's results for single passes. The present work gives results quite different from those of the other investigations; it is only at very light reductions that there is any agreement at all. The explanation of this difference in behaviour can probably be found in the very different rolling conditions and experimental techniques. Baker *et al.* used bearing-bronze and Hsiao aluminium specimens, which were much thicker (0·33–1·0 in.) than those used in the present work.

A few experiments were carried out to check whether the use of a different material would, in fact, give different residual-stress distributions after rolling; 14-S.W.G. O.F.H.C. copper strip was chosen for this purpose and samples were rolled 0·5%, 1·0%, 2·6%, and 5·5% reduction in single passes using 7-in. dia. rolls. The residual stresses were determined as described in an earlier section (using 25% instead of 10% nitric acid), and the results are given in Fig. 9. The residual-stress distributions are rather different from those obtained using mild steel, the main difference being the presence of a high compressive surface stress, even at a reduction as high as 5·5%. It is interesting to speculate whether this surface compressive stress might be connected with the surface hardening which occurs when annealed copper is rolled lightly (up to about 10% reduction), but which cannot be detected in lightly rolled steel specimens.[18] It is not really possible to plot the residual stresses in rolled copper in the way suggested by Baker *et al.*, but it seems that the general level of residual stress (if compared with the yield stress) tends to decrease as the reduction is increased from 1% to 5·5%. This is in agreement with the results of the earlier workers, and suggests that the discrepancies between their results and the present ones may be due to the different materials.

On one point, however, the present work is in full agreement with the findings of Baker *et al.*, namely that it is the final pass only that decides the residual-stress distribution. Figure 10 shows an example of this. Two strips were rolled 4% and 6% in single passes and were then given another pass of 4%; the residual-stress distribution is very similar in both

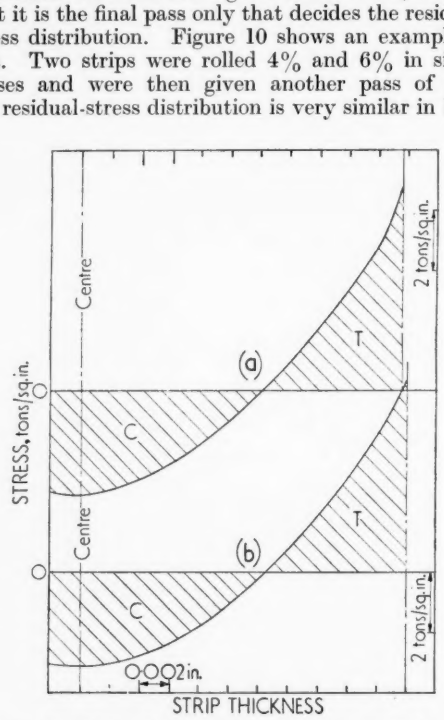


Fig. 10—Residual-stress distributions in rolled mild-steel strip: (*a*) Rolled 6% in one pass followed by 4% in a second pass; (*b*) rolled 4% in one pass followed by 4% in a second pass

cases and is similar to that for a 4% pass on annealed strip (Fig. 6*g*).

Examination of Fig. 6 also shows that there is a gradual change in the residual-stress distribution as the reduction is increased. A surface compressive stress is induced for the lightest reduction and, as the reduction is increased, this decreases in magnitude and changes to a tensile stress. As the reduction is increased still further, the surface stress increases, until eventually the maximum stress is found in the extreme surface layers. The surface stress in rolled copper apparently behaves in a similar manner to this (Fig. 9), and other workers have noted similar effects. Bühler and Buchholtz[19] determined the residual stresses in drawn steel rods. They found that at low reductions the surface stress was compressive, and as the reduction was increased the stress gradually became tensile; the change in sign of the surface stress occurred at about 0·8% reduction. Surface compressive stresses due to similar metal-working operations have also been observed by Hsiao[9] in the rolling of aluminium and by Loxley and Whiteley[20] in the drawing of steel tubes. These workers, however, found surface compressive stresses to be present at high reductions: Hsiao, using an X-ray technique, observed a residual surface compressive stress in all his specimens (up to 30% reduction), and Loxley and Whiteley found the same in heavily drawn tubes (about 40% reduction), using the Sachs–Espey analysis. On the other hand, however, neither Baker, Ricksecker, and Baldwin[4] nor Treuting and Read[14] observed a surface compressive stress in their rolled specimens, and it might be that this only occurs under certain conditions of working. It must also be remembered that very accurate methods of measurement would be needed to detect rapidly varying stresses in a very thin surface layer, and it is possible that such stresses in thin specimens might not be easily revealed by the normal methods of analysis.

A number of the curves in Fig. 6 show signs of a protuberance midway between the core of the sheet and the surface, and Loxley and Whiteley[20] observed a secondary peak in the tensile residual stress at a similar position in drawn steel tubes. Microhardness traverses across a section cut from rolled or drawn steel often show a peak at a similar position,[18] and it is possible that the two phenomena are connected in some way. The specimens used in the present work were too thin for an accurate microhardness traverse to be obtained, but, for comparison, a curve taken from some earlier work on a thicker sample of drawn mild steel is shown in Fig. 11.

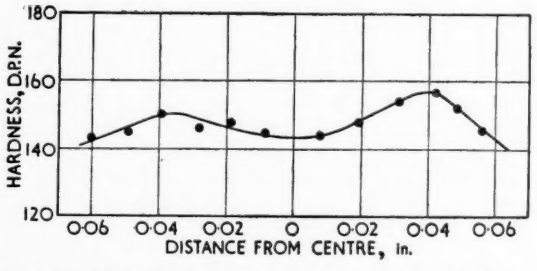


Fig. 11—Microhardness traverse across the thickness of a mild-steel wire drawn 4% reduction in area through a 20° die

CONCLUSIONS

Unidirectional residual stresses which vary through the thickness of a thin sheet-steel specimen may be determined by etching away one face of the specimen and measuring the corresponding change in curvature. The reproducibility of the results is good and the analysis is not very tedious. If a number of specimens are tested at the same time, the thickness/curvature relation for each specimen can be obtained in about 8 hr., and the residual-stress distribution can be calculated from these results in about 2–3 hr. Although the method described has a particular application to mild steel, it can be applied with equally good results to other metals, such as copper.

It was found that the magnitude and distribution of the residual stresses in rolled mild-steel strip changed as the rolling reduction was varied (up to 6% reduction). Generally the residual stresses increased in magnitude as the reduction was increased. In rolled copper strip, on the other hand, there was a tendency for the residual stresses to decrease slightly as the reduction was raised.

Acknowledgment

The author would like to thank Mr. E. M. Loxley for his useful suggestions in the initial stages of this work.

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The Mechanism of the Reduction of Iron Oxides by Solid Coke

By B. G. Baldwin, B.Sc., Ph.D., A.R.I.C., D.I.C.

SYNOPSIS

The mechanism of the reduction occurring in a heated bed of iron oxide and coke has been studied. The reduction is shown to occur almost exclusively by gaseous reactions in which a molecule of CO reduces the iron oxide and the CO_2 produced reacts with the coke to give two molecules of CO_2 which are available for further reduction. The application of these results to the study of the blast-furnace process is discussed. 1010

Introduction

In general two hypotheses have been put forward to account for the reduction of iron oxide which occurs when a mixture of oxide and carbon (coke, graphite, deposited carbon, etc.) is heated. These can be represented as follows:

$$\underset{\text{(solid)}}{Fe_xO_y} + \underset{\text{(solid)}}{C} \longrightarrow \underset{\text{(solid)}}{Fe_xO_{(y-1)}} + \underset{\text{(gas)}}{CO} \quad \ldots\ldots(1)$$

$$\left.\begin{aligned} &\underset{\text{(solid)}}{Fe_xO_y} + \underset{\text{(gas)}}{CO} \longrightarrow \underset{\text{(solid)}}{Fe_xO_{(y-1)}} + \underset{\text{(gas)}}{CO_2} \\ &\underset{\text{(gas)}}{CO_2} + \underset{\text{(solid)}}{C} \longrightarrow \underset{\text{(gas)}}{2CO} \end{aligned}\right\} \quad \ldots\ldots(2)$$

where $x = 1, 2,$ or 3
when $y = 1, 3,$ or 4.

Thermodynamic considerations cannot assist in deciding which is taking place, as the total reaction is identical in both cases. The view most widely held at present is that the two-stage hypothesis (2) is the more probable (*e.g.*, Esin and Gel'd[1]).

However, Tammann and Zvoruikin[2] and Baukloh *et al.*[3–6] supported the first hypothesis. Baukloh *et al.* tried to establish a parallelism between the first products of solid–solid reduction and the dissociation pressures of the oxides. Although these authors claimed to have overcome the great difficulties associated with thorough degassing of the reacting substances and the interaction of the products of reduction, some of their experimental results do not substantiate this. The preliminary dissociation of the oxide to give oxygen, which then combined with the carbon, was proposed by Tammann and Zvoruikin.[2] The calculations of Gel'd and Esin[7,8] of the dissociation pressure of FeO showed that the amount of dissociated oxygen available was insignificant compared with the actual amount of reduction occurring. This would seem to render the above hypothesis untenable. Baukloh and Durrer[3] suggested that diffusion of solid carbon was the rate-determining process. Baikov and Tumarev,[9] however, showed that the reduction of the oxides of copper and silver, in which carbon does not dissolve, occurred when they were heated with carbon.

The high reactivity of carbon formed by the graphitization reaction in the interstices of an iron ore was shown by Bone, Reeve, and Saunders.[10] At 750° C. the carbon deposited within the pores and interstices of ore granules was found to reduce the material even more rapidly than gaseous CO at the same temperature. This has also been confirmed by later workers. The significance of this, from the practical aspect, has been emphasized by Saunders and Tress.[11]

Experimental data suggest that, of the two reactions comprising the overall solid–solid process, the solution of carbon (*i.e.*, the reaction $CO_2 + C \rightarrow 2CO$) is the slowest. The reactivity of different carbons as measured by the reaction of iron ore with carbon was shown to vary in the same way as their reactivity towards CO_2 in the carbon-solution reaction. Williams and Ragatz[12,13] found an increase in the reaction rate of heated mixtures of coke and iron ore by the addition of Na_2CO_3. In all, 43 substances were investigated, mainly oxides and carbonates. This tends to confirm the hypothesis that the rate-controlling process of the ore–carbon reaction is the rate of carbon solution, since these substances are known to have a strong enhancing effect on the reactivities of carbon to CO_2, as shown by the work of Taylor and Neville[14] and others.

THE PRESENT INVESTIGATION

This work was begun with the aim of investigating the theory that interaction of carbon and iron oxide occurs by a two-stage mechanism and of comparing the reduction obtained in a heated bed of ore and coke with that occurring by gaseous reduction of a bed of ore in a $\frac{1}{3}CO$, $\frac{2}{3}N_2$ gas mixture. The iron ore chosen was a pure hematite (Itabera), having an analysis of 98% Fe_2O_3, 1·7% Al_2O_3, and 0·3% SiO_2, which was selected in an attempt to avoid complications associated with the presence of impurities. A Durham dry-quenched coke was used. Experiments were carried out on three sizes of ore and coke: 8–10, 10–16, and 20–30 B.S.S. mesh; 5 g. of ore and

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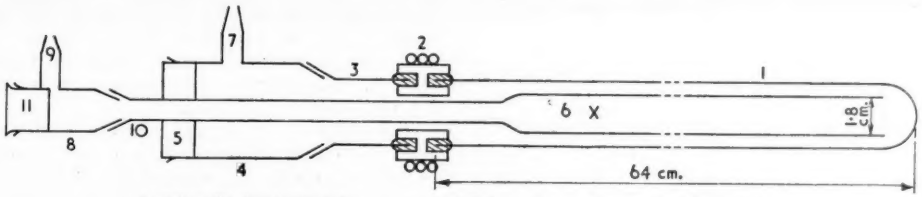

1. Externally glazed silica tube
2. Water-cooled brass connector
3. *B*29 Pyrex socket
4. *B*29 Pyrex cone
5. Rubber bung
6. Reaction tube
7–9 *B*7 Pyrex cones
10. B7 silica socket
11. Rubber bung

Fig. 1—Diagram of apparatus

3·5 g. of coke were used in each experiment, the ore and coke being of the same size grading. The relative amounts of ore and coke used are similar to those present in the blast-furnace burden.

APPARATUS

The apparatus is shown in Fig. 1. Gas entered by a *B*7 Pyrex cone (7) and left by joint 9 as shown. A chromel/alumel thermocouple passed down the centre of the silica tube (6), the junction being in the centre of the ore charge, which was placed at *X*. The exit leads passed through the joints (8) and (10) and out by the sides of the rubber bung (11), which was waxed into position. The gas passed down the outside of the ore container and then back through the centre of it through the charge.

The charge was kept in position by mullite chips which were packed on either side of the charge in the silica tube (6). This tube was also filled to the end with additional mullite chips to preheat the gas.

EXPERIMENTAL METHOD

The original scheme was to heat up a bed of ore and coke to the required temperature in a stream of nitrogen and to analyse the exit gases for CO and CO_2. Meyer[15] showed that the amount of reduction occurring in a heated mixture of iron oxide and carbon was influenced by the rate of flow of an inert gas over it; this has been neglected by subsequent workers. Direct interaction of ore and coke should be independent of the gas flow, and so it was decided to investigate the phenomenon more fully; preliminary experiments confirmed that the rate of gas flow did affect the rate of reduction.

One of the difficulties in experimental work on solid–solid reactions is that of obtaining reproducible packing. A modification of a method used by Klemantaski[16] (for the study of the reduction of iron ores by hydrogen) enabled the rate of reduction at different percentages of oxygen removed to be determined over a wide range of gas flows, using the same bed of material.

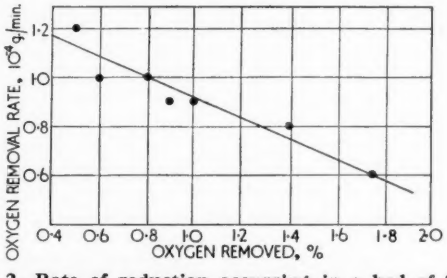

Fig. 2—Rate of reduction occurring in a bed of 8–10 mesh ore and coke at 900° C.; gas flow rate 2 c.c. of nitrogen per sec.

When the ore and coke mixture had been placed in the reaction tube, the system was first evacuated and then filled with pure nitrogen. The charge was then heated to the required temperature. During this heating a high flow (30 c.c./sec.) of nitrogen was passed through the apparatus. When thermal equilibrium had been reached, the flow of nitrogen was varied from time to time over a wide range; the exit gas was analysed for CO and CO_2 for each change in gas flow.

The gas leaving the apparatus was passed through a weighed Midvale tube containing Sofnolite to remove CO_2, mixed with oxygen and passed over heated copper oxide, and then passed through a second weighed Midvale tube to absorb combusted CO.

During a typical run at 1000° C., gas flows of 1, 3, 5, 7·5, and 10 c.c. of nitrogen per sec. were employed. These flows correspond to a linear velocity in the empty reaction tube (6) of 1·8, 5·5, 9·2, 13·7, and 18·3 cm./sec. at 1000° C. When thermal equilibrium was reached the gas flow was usually decreased rapidly to the lowest value to be used; two Midvale tubes were connected, one to absorb CO_2 and the other combusted CO. Ten minutes were allowed to elapse when, with the gas flow constant, the two tubes were replaced by two more weighed tubes. The time of use of this new pair varied from 10 to 30 min., depending on the rate to be expected. At the end of the allotted time these tubes were replaced by the original pair, which had since been reweighed, and the flow rate was adjusted to its new value. These were kept in position again for 10 min., when the procedure was repeated.

The purpose of this double arrangement was as follows. Owing to the large variation in rate which occurred between the highest and lowest values (often 10 : 1) of the gas flows, an appreciable error would be introduced when passing from one rate of flow to the other, because of the finite time taken by the gas to travel through the analysing system. For the first few seconds after a change of flow, the gas passing through the system was associated with the former flow but would be analysed as coming from the latter. The reason for connecting these two preliminary tubes at all, and not passing the gas to waste, was to enable the extent of reduction

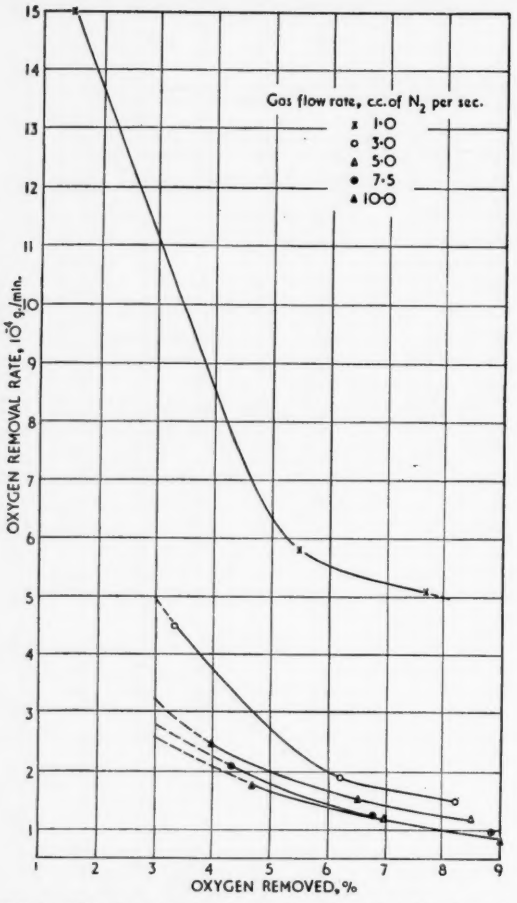

Fig. 3—Effect of variation in the flow of nitrogen on the reduction occurring in a bed of 8–10 mesh ore and coke at 1000° C.

of the system to be calculated. The rates of reaction were calculated from the increase in weights of the second pair of tubes and the time of use.

CALCULATION OF RESULTS

The weights of CO_2 and combusted CO absorbed were converted to grams of oxygen removed, and hence the grams of oxygen removed over the period of use of the Midvale tubes were determined. The rate of reduction of the ore, in grams of oxygen removed per minute, was calculated from the gain in weight of the second pair of Midvale tubes. The values for the time and percentage of oxygen removed, corresponding to this rate, were taken as the mean over the period of use of that pair of tubes. The total percentage of oxygen removed was calculated by knowledge of the total oxygen available and of the amount actually removed.

EXPERIMENTAL RESULTS

Experiments were carried out at 800°, 900°, and 1000° C. The rate of reduction occurring in the bed heated at 800° C. was found to be extremely small (the percentage of oxygen removed was only 0·21 after 1 hr. with a gas flow of 2 c.c./sec.). The rate was also found to be very small for reduction at 900° C. The results obtained are shown in Fig. 2 for a gas flow of 2 c.c./sec.

The removal of oxygen from a heated ore–coke bed was found to proceed to a very much greater extent at 1000° C. The effect of the change in flow rate of nitrogen is clearly shown in Fig. 3. The CO and CO_2 contents in the exit gas were analysed during a total period of 6½ hr., at which point the experiment was stopped; about 9% of the available oxygen had been removed from the ore at this stage. An increase in the rate of flow of nitrogen decreased the amount of oxygen removed. Figure 4 shows the effect of rate of gas flow on the rate of reduction for differing percentages of oxygen removed from the bed. At high rates of flow a limiting value for the rate is reached, which is unaffected by further increase in gas flow. The results obtained with lower rates of gas flow are shown in Fig. 5, together with some curves obtained at higher flows for the purpose of comparison. At the early stages of the reduction the rate of oxygen removal with a slow speed of gas (¼ c.c./sec.) is nearly 50 times that with a high rate of flow. It would appear that more than one process is occurring at the same time: one strongly dependent on the speed of the inert gas through the bed and the other independent of this flow.

If the latter process is the direct interaction of ore and coke, it would presumably be affected by the intimacy of packing, since the smaller the size the greater the number of contacts between the particles.

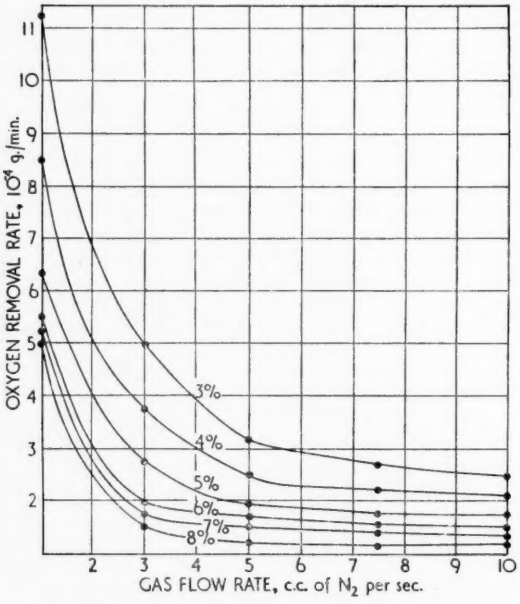

Fig. 4—Effect of variation in the flow of nitrogen on the reduction occurring in a bed of 8–10 mesh ore and coke at 1000° C. for various percentages of oxygen removed

Hence a series of experiments were carried out at 1000° C. with smaller-size Itabera ore and coke. The sizes chosen were 10–16 and 20–30 mesh. The results obtained with 10–16 mesh ore and coke are shown in Fig. 6*a*. Again there is considerable removal of oxygen from the bed with low rates of gas flow. The results obtained with 20–30 mesh material are shown in Fig. 6*b*. Here there is an increase in the rate at the lower flows compared with those obtained for the two previous series (*see* Figs. 5 and 6*a*). If a visual extrapolation is made of the graph for the rate of ¼ c.c./sec. to about 4% of oxygen removed, the rate at this flow is about 150 times that occurring at high rates of gas flow.

DISCUSSION OF RESULTS

The experiments at 800° and 900° C. showed that the rate of reaction was extremely slow. The rate at 1000° C. was considerably greater than at the two lower temperatures. It is difficult to see the precise effect of temperature, but the relative rates at 900° and 1000° C. are of the order of 1 : 10.

Experiments carried out to measure the influence

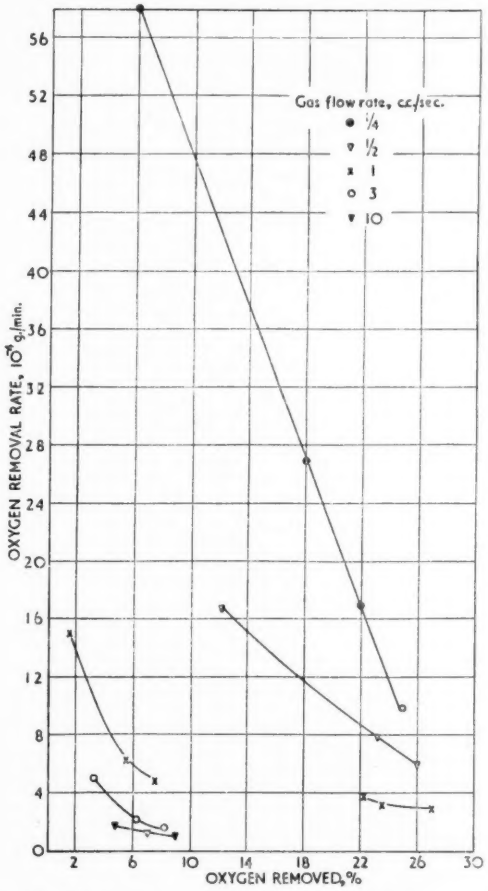

Fig. 5—Effect of very slow flows of nitrogen on the reduction occurring in a bed of 8–10 mesh ore and coke at 1000° C.

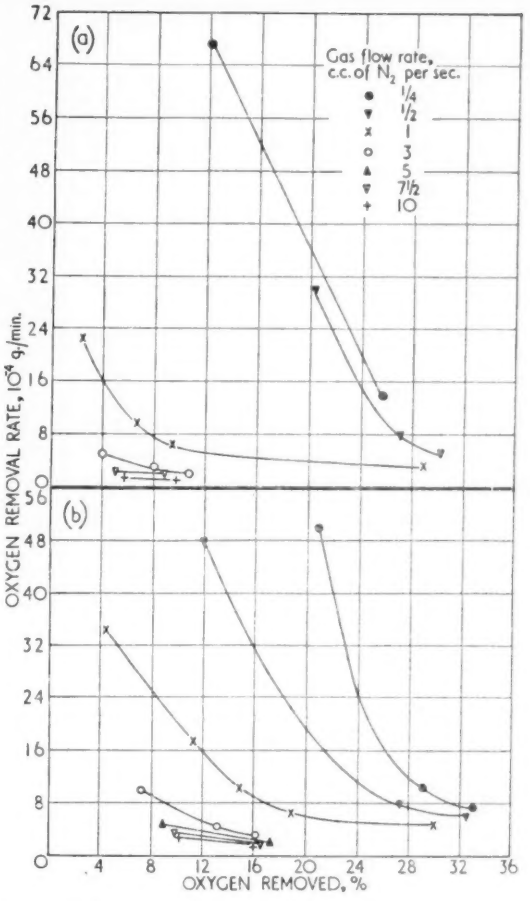

Fig. 6—Effect of variation in the flow of nitrogen on the reduction occurring in a bed of (*a*) 10–16 and (*b*) 20–30 mesh ore and coke at 1000° C.

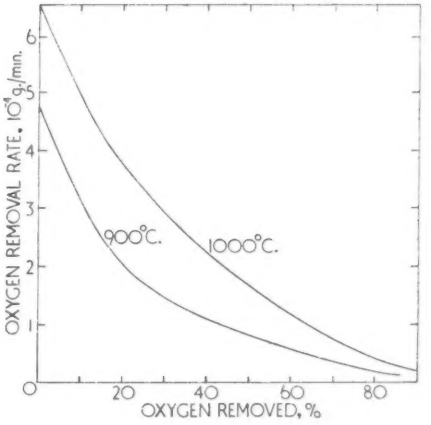

Fig. 7—Rate of reduction of 8–10 mesh ore in ⅓CO, ⅔N_2 gas mixtures

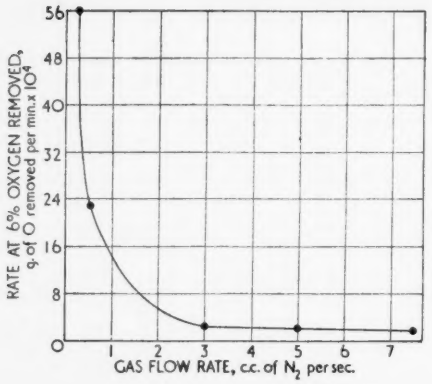

Fig. 8—Variation in the rate of reduction occurring in a bed of 8–10 mesh ore and coke at 1000° C. with change in the flow of nitrogen at 6% of oxygen removed

of temperature on the gaseous reduction of Itabera ore by a gas mixture of $\frac{1}{3}$ CO, $\frac{2}{3}$ nitrogen, showed that the ratios between the rate at 900° and 1000° C. at 2% of oxygen removed were of the order of 3 : 4 (*see* Fig. 7). These results were obtained by reducing a bed of 8–10 mesh Itabera ore mixed with mullite chips equal in volume to the coke used in the other experiments. The reduction was followed by weighing the CO_2 evolved. The results are fully reported elsewhere.[17]

The effect of variations in the gas flow through the bed on reduction occurring is pronounced. With increasing gas flow the rate of removal of oxygen decreases until a point is reached where further increase has no effect on the rate. This is shown in Fig. 4 for a bed of 1000° C., and for the purpose of this discussion the rate of flow at this point can be considered as infinite. As the gas flow is diminished from this value the rate increases considerably, until with a low flow of $\frac{1}{4}$ c.c./sec. the rate of reaction is 56 times that at an infinite flow for 6% of oxygen removed; this is shown in Fig. 8.

The mechanism envisaged to account for these results is a type of chain reaction. A molecule of CO is formed in the bed; this reduces the iron oxide to give CO_2, which then reacts with coke to produce two molecules of CO, which are available for further reduction. This is equivalent to the second mechanism referred to in the Introduction.

In the present work a certain finite rate of reaction is obtained which is independent of further increase in flow. This suggests that a small but definite amount of solid–solid reaction is occurring (this would not be affected by the flow of gas through the bed). An initial source of CO is required to start the ' chain ' process, and it is considered that this source is produced by solid–solid reaction at the points of contact of ore and coke. It is this reaction which is being measured at an ' infinite ' rate of gas flow. If gas–solid reactions were the only ones occurring in the heated bed of ore and coke, a sufficiently rapid flow of inert gas would diminish their rate almost to zero, as the gases would be swept out of the bed before having time to react with solid material.

The solid materials may contain appreciable amounts of adsorbed oxygen, which will tend to desorb at high temperature and could then provide the necessary CO to initiate the reaction. It is felt, however, that desorption was probably as complete as possible before the experiment was begun and the products of desorption were removed in the very rapid nitrogen stream which was passed through the bed (30 c.c./sec.).

Two types of reaction are occurring together, one between solid coke and solid ore and the other involving the gaseous reduction of iron ore and the solution of coke by CO_2. The latter process is almost completely stopped by a sufficiently rapid flow of gas through the bed. The reaction between ore and coke can proceed only at the points of contact, so that once iron is produced at these positions the reaction will slow down considerably. It might be thought that this reaction should slow down more rapidly than those involving gases, but this is not found. The change in the rate of reaction with amount of reduction for an infinite flow is very much less than that with a very small flow of inert gas through the bed. The rapid rate of reduction which occurs at the beginning of reduction with a low flow of gas through the bed can be explained in the following way. The reduction of Fe_2O_3 to Fe_3O_4 is practically irreversible at high temperatures and the values of the CO/CO_2 ratio at equilibrium are about zero. Hence when CO is passed slowly over heated Fe_2O_3, practically every carbon monoxide molecule can react with the oxide to give CO_2. A large fraction of this CO_2 can react with coke to give CO, since the concentration of CO will be low, and hence the reduction of the iron oxide will be very rapid. As soon as Fe_3O_4 is produced on the surface and reduction proceeds to FeO, the equilibrium is less favourable to gaseous reduction and CO regeneration, and hence a rapid fall in the component of the reduction, which occurs *via* the gas phase, is to be expected.

The rate of reduction increases very considerably both for the highest and lowest flow rates used (10 and $\frac{1}{4}$ c.c. of nitrogen per sec.) for a decrease in particle size; this is shown by the following results:

Particle Size (B.S.S. Mesh)	Rate at 20% of Oxygen Removed with Flow of $\frac{1}{4}$ c.c. of N_2 per sec.	Rate at 10% of Oxygen Removed with Flow of 10 c.c. of N_2 per sec.
8–10	22·4	0·75
10–16	36·0	1·40
20–30	50·5	3·10

The rate at high (or infinite) gas flow has increased with decreasing particle size, as would be expected if this did represent a small amount of solid–solid interaction. The rate of reaction is very rapid at low gas flows, and this may be due to a number of factors. Increased solid–solid reaction causes an increase in the initial supply of CO in the bed. The ore and coke surfaces are greater, thereby facilitating reduction and CO regeneration, and, because the average coke-ore distance is smaller (and hence the distance a CO or CO_2 molecule will have to travel before reacting will be less), the chance of its being

'swept' out of the bed before reacting will be diminished.

The considerable difference in the observed rates of reduction between 900° and 1000° C. can give an indication of the relative rates of the two gaseous reactions. It has already been mentioned that the change in the rate of gaseous reduction of Itabera ore between these temperatures is not very considerable (Rate $_{900°C.}$: Rate $_{1000°C.}$ = 3 : 4), but it is well known that the temperature coefficient of the CO_2/coke reaction shows very great changes in this temperature range. It is difficult to obtain an exact comparison of the rate of carbon solution at 900° and 1000° C., but it is of the same order as the change in the rate of the reduction occurring in the bed. It is likely, therefore, that in the early stages of reduction the rate of solution of carbon is controlling the overall process. This is in agreement with the results of other workers which have already been reviewed.

The observation of Bone, Reeve, and Saunders[10] referred to earlier is considered to be due to the following condition. The pores of the ore in this case were filled with deposited carbon which in its finely divided state is very reactive towards CO_2. Thus the regeneration of CO will occur instantaneously within the ore particles themselves, with consequent rapid reduction.

From the practical point of view these results show that, if a bed of ore and coke is heated, the reduction which takes place (in the absence of a very rapid inert-gas flow through the bed) occurs by a two-stage mechanism, the ore being reduced by CO and the coke consumed by the CO_2 produced during the reduction of the ore. The amount of reduction occurring as a result of the direct interaction of oxide and coke can be ignored. From this it follows that the amount of reduction occurring depends on two factors: (i) the ease of gaseous reduction of the oxide and (ii) the ease of solution of the coke by CO_2. It is evident that investigations on the reaction occurring in a heated bed of oxide and coke do not measure the extent of the actual solid–solid reaction between ore and coke, but merely some factor depending on factors (i) and (ii). Since it has been shown that in the initial stages of reduction the gaseous reduction of the oxide is considerably greater than that of the solution of coke by CO_2, it follows that this latter reaction is controlling the overall process, and it is some function of this which is actually being measured at the beginning.

Considering the practical problem of the so-called 'direct' reduction occurring in the blast-furnace, it is not proposed to enter into the argument about whether or not this should be sought, since this has already been discussed by Taylor.[18]

The results of the present investigation have enabled the amount of reduction occurring in a heated bed of ore and coke by interaction of the two solid materials and by gaseous reactions to be measured, and it is evident that the latter process is very much greater than the former, which is to be expected in the blast-furnace.

When iron ore is reduced by CO, and the CO_2 produced reacts with solid coke to form CO, this is stoichiometrically and thermally equivalent to the reaction between solid coke and solid iron oxide, and hence 'direct' reduction in the blast-furnace must be considered as the consumption of coke by the CO_2 produced by the gaseous reduction of the ore. If the complete reduction of the ore can take place before the reaction of $CO_2 + C \rightarrow 2CO$ proceeds in this direction, no 'direct' reduction can occur. Published data suggest that, under the conditions prevailing in the blast-furnace, 'direct' reduction begins at about 900° C. The results obtained by Wild and Saunders,[19] who measured the reduction of lumps of different ores under conditions similar to those occurring in the blast-furnace, give a rough indication of the amount of 'direct' reduction these ores may undergo in the furnace. They stopped their experiments at 940° C., and the amount of iron oxide left in the ores at this stage is an indication of the amount of direct reduction which will take place. This is because part of the CO_2 produced during the final reduction of the ore will be able to react with the coke. Owing to equilibrium and physical conditions, every molecule of CO_2 evolved by reduction of the ore will not react with coke, and so it is not possible to obtain an exact measure of the amount of direct reduction which is taking place. However, the amount of direct reduction is probably qualitatively related to the amount of oxygen left in the ores at the completion of their experiments.

'Direct' reduction affects the distribution of heat in the furnace, since the carbon solution reaction is strongly endothermic and the solution of coke by CO_2 results in less coke being available for combustion in the tuyere zone. When deposited carbon (not coke) is used up by carbon solution, the amount of coke reaching the tuyeres is unaffected. Excessive 'direct' reduction will result in insufficient heat in the lower part of the furnace unless extra coke is charged to compensate for this. The extent to which this occurs can be diminished by increasing the amount of reduction of the ore taking place below 900° C., and this can be accomplished in two ways: by finer crushing of the ore, or by reconstitution of the ore in a more reducible form.

As the temperature rises above 1200° C. the rate of direct interaction of oxide and coke may increase to such an extent that it may not be true to dismiss entirely its contribution to the overall reduction. This is likely to be important when the ores used are not pure iron oxides but contain impurities. For example, the formation of fayalite occurs at elevated temperatures (*e.g.*, Baldwin[20]) from FeO and SiO_2, and, as is well known, this substance is difficult to reduce and has a relatively low melting point (1205° C.). At temperatures near the melting point, glazing of the ore, which would diminish the ease of gas penetration, would occur; at higher temperatures molten fayalite would drip on to coke particles, and the conditions for the direct interaction with coke would arise. There are, however, no published data on this type of reduction process, which is obviously of some importance.

Acknowledgement

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The International Research Committee on the Low Shaft Furnace

RESULTS OF ONE YEAR OF OPERATION 1953–54

The basic principles of the development of the low shaft furnace at Ougrée were laid down[1] in 1952 by the Directing Committee, which includes representatives of the seven participating countries—Austria, Belgium, France, Greece, Holland, Italy, and Luxembourg—together with the U.S. Battelle Memorial Institute. The subject was dealt with more fully in May, 1953, at the *Journées Internationales de Sidérurgie* at Liège[2] by its President. In addition, a paper was presented describing the main characteristics of the pilot plant, including some constructional details.[3]

The carrying out of the research was entrusted to the Liège section of the *Centre National de Recherches Métallurgiques* and effected with the aid of the local iron and steel industry and the co-operation of Belgian, French, Italian, and Luxembourgeois investigators, which thus maintained its international character.

It is to be remembered that in Western Europe, the main interest in the low shaft furnace lies in the manufacture of iron from such raw materials as interfere with the smooth operation of blast-furnaces or which cannot be treated in the blast-furnace at all.

Notwithstanding this, in order to gain familiarity with the reactions of the plant, to facilitate comparison of results with the blast-furnace and not to have to cope with all the difficulties at once, the Committee decided on a progressive and flexible programme of trials. This was the more justified in that the initial trials involved no preparation of the charge.

The main lines of the programme can be summarized as follows. Initially the fuel should be a metallurgical coke of a size too small for effective use in the blast-furnace.

Thereafter the trend should be to use cheaper fuels such as semi-coke, low volatile fines, etc., which could not be used in the blast-furnace.

Correspondingly, the ore should be from Lorraine or Luxembourg with a size grading similar to that obtained by screening after crushing. As an example, the initial raw material might be sized 10–20 mm. with subsequent trials employing an increasing proportion of 0–10 mm. These conditions were thus very different from those previously encountered in low shaft furnace practice, such as in making ferromanganese and ferrosilicon, where the high coke rate ensures good stack permeability, or in manufacturing

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iron from sized agglomerates of ore and fuel, raw or fired.

It will be recollected that in order to provide data applicable to industry and to avoid excessive thermal losses per ton of iron, the Committee had decided to build a unit on a reasonably large scale, corresponding to a hearth area of 3 sq. m. The form of the cross-section was chosen in view of the fact that the classical circular form imposes relatively large distances between the noses of the tuyeres and generally results in an inert zone in the centre. It was considered that this arrangement might be an obstacle to the treatment of the small-sized ore envisaged; it appeared indeed necessary to arrange that such materials should pass through the combustion zone at the tuyeres, thus ensuring that they should not descend in an ill-prepared state to the hearth where they are incorporated more or less in the slag and introduce oxygen into the iron already produced.

This necessity to work in a narrow region and the practical impossibility of building an annular arrangement led to the construction of a low shaft furnace of oval section.

The dimensions arrived at by the Committee (an oval of 9·84 ft. × 3·94 ft. and a height of 19 ft. from the bottom of the hearth to the normal stockline) demanded the distribution of the charge by a double charging device, which should be sufficiently gas tight to permit eventual operation at high top pressure.

The first campaigns of the low shaft furnace at Ougrée* thus involved experimentation with completely new equipment using entirely unfamiliar raw materials. It was difficult to follow any other course bearing in mind that the alternative of starting from preliminary experiments with classical materials would have given little indication of the reactions of the equipment to the raw materials to be used later. The first trials were marked by a number of breakdowns and incidents attributable neither to the overall principles of the installation nor to the materials charged. Nevertheless, despite these difficulties, between 13th May, 1953, and 6th July, 1954, in the course of three campaigns producing 7000 tons of iron, it has been possible to make a considerable number of observations which have, for the most part, been supported by frequent measurements and analyses.

Commencing with limy and siliceous Luxembourg ore of 26% Fe, sized 10–30 mm., but containing 20–30% of 0–10 mm., and with a small coke (10–30 mm.) first from Ougrée and then from Cockerill, the trials were continued with Lorraine ore from Piennes (34% Fe, 10–20 mm., but with 30–50% of 0–10 mm.) and with coke from Ougrée, Zeebrugge, and Cockerill, together with additions (amounting to 20% of the carbon) of coke breeze. Finally, the last campaign employed the Lorraine ore Ida (31·5% Fe, 10–20 mm. with only 8% of 0–5 mm., rising to 14%) with semi-coke from Bruay (12% volatile matter), then this same coke with the addition firstly of 25% of coal (24% v.m.) and finally of anthracite (12·5% v.m.).

Hot blast at about 700° C. has been used with or without enrichment by oxygen, normally to 28% O_2.

The detailed reports give a critical analysis of all these trials from which the following observations are of particular importance.

The segregation of materials on charging plays an absolutely vital role, the low inertia, small height, and narrow section of the furnace making it extremely sensitive to irregularities in burden composition. Moreover, irregular distribution of the materials, as in all shaft furnaces, gives rise to asymmetry in the working of the furnace involving partial fusion too high up in the stack in certain points and, on the other hand, appearance of unprepared material in the hearth at others. It is therefore essential to ensure perfectly regular feeding with uniform distribution of the materials over the entire cross-section.

It has been observed in the course of trials (with fine ores) that relatively large coke (20–40 mm.) gives a better permeability in the stack, but that on the other hand the zone of high temperature rises and the quality of the iron suffers involving, in particular, a low carbon content and an increase in silicon, while removal of iron and slag becomes difficult. One may conclude from this that it is necessary to charge coke sized 10–20 mm. approximately, more close to the ore size. In particular, iron quality has improved, especially in carbon content, by the addition of very small coke (breeze) to the charge. On the other hand, a large proportion of this breeze turns up in the flue dust where the carbon content may rise to 30–40%. Excellent results have been given when using Bruay semi-coke below 20 mm. with 10–12% volatile matter. With this fuel and Ida ore and operating with a burden yield of 28·6% (dust losses allowed for), a carbon rate of 22·9 cwt./ton (excluding dust losses) has been attained. The dust losses were about 6·0 cwt., half of which was extremely fine ore (below 500μ) and the other half fine semi-coke. This operation, with a blast of 28% of oxygen, gives a gas of 152 B.Th.U./cu. ft. and an iron of low Si (0·2%), high C (3·66%), and acceptable S (0·115%). These results, obtained with equipment not fully developed, can probably be improved upon and are encouraging. They show that a normal Thomas iron can be obtained from fine ore and a fuel based on non-coking coal. The daily output during these trials was about 40 tons.

Trials on the utilization of coal (24% v.m.) and anthracite (13% v.m.) have also been carried out with 28% of oxygen, but using only 25% of these coals added to the semi-coke. These trials were somewhat sporadic and the only conclusions of importance which need be mentioned are: the top gas contained no tar and hardly any hydrocarbons, but had a high hydrogen content. It might thus be thought that the employment of enriched air brings about the existence of a small combustion zone with a high temperature gradient and a relatively cold stack, so that the hydrocarbons are decomposed before being picked up by the gas. This encourages further trials using raw coals, at least anthracite.

We have referred to the high thermal concentration brought about by enriched air; this was expected and the consequent low top temperature is precisely the phenomenon which makes it possible to have a low shaft.

* A detailed report of these trials is now in course of publication.

It may be said that in the course of several smooth trials, giving good observations with a blast of 28% of oxygen and at 700° C., the top temperature rarely exceeded 150° C. and the height above the tuyeres of the zone of red heat did not exceed 4 ft. The temperature then fell rapidly to 200° C. or even 100° C. in the zone immediately above. This explains why, in spite of the high content of CO or even hydrogen, the gas brings about a negligible degree of reduction. The increase in coke rate for direct reduction which results is partly compensated for by the increased value of the top gas which would naturally have to be evaluated according to local conditions.

The oxygen content of the blast has been carried up to 32% in the course of the trials without leading to any particular conclusions. The enrichment has generally been maintained at about 28%. It is evident that in the course of future campaigns it will be desirable to proceed in steps in order to determine, for a given burden, the optimum oxygen content to obtain at the same time a sufficiently low top gas temperature, rate of output appropriate to the low shaft furnace, regular descent of the stock, and a sufficiently low dust loss. It is possible that the use of high top pressure will permit an appreciable reduction in the oxygen requirement and thus make the operation less costly, but certain shortcomings of the furnace top have so far not permitted this to be done.

It has been observed, as was anticipated, that the low shaft furnace accepts with difficulty high blast volumes of normal air, the trials carried out on these lines having brought about extensive hanging 'chimneying,' high top temperatures, and very large dust losses. Fortunately it may be observed that the thermal efficiency of the apparatus is excellent, a phenomenon probably due to the concentration of the high-temperature zone; the thermal losses of this furnace producing some 40 tons of iron per day amount to barely 10% of the total, not as great as those observed in a normal furnace with high output.

Another consequence of the use of oxygen and of the high temperatures thus attained is that it seems possible to utilize extremely basic slags ($CaO/SiO_2 = 1{\cdot}7$–$1{\cdot}8$) resulting in a high-temperature iron (1400–1500° C.) and consequently, despite the high sulphur input, to produce low-silicon irons of which the sulphur content does not exceed 0·125%. On the other hand, it seems that the existence of a narrow zone of very high temperature with cold material above brings about (as in certain electric furnaces or producers) the formation of partially fused layers in the form of an arch which oppose the regular descent of the burden. On several occasions it has been possible to demonstrate the existence of such crusts at the limit of the combustion zone by probing vertically with steel bars.

It is probable that systematic movement by small scale hanging and slipping in a more or less regular manner which has always been observed on the low shaft furnace blown with enriched air, is due to the existence of these crusts. It is possible that in future better distribution of the materials will partially remedy this inconvenience as may also the studies on optimum oxygen requirements. The phenomena of hanging which throughout the trials have made the control of the low shaft furnace delicate, are also influenced by other causes, particularly the presence of very fine fractions in certain of the ores used.

If it has been clearly demonstrated that the low shaft furnace can consume satisfactorily material of 5–20 mm., for example, it is also clear that it acts as a deduster for the very fine fractions such as particles below 500μ and particularly below 300μ. Concurrently, with an increase in flue-dust make, it has been observed that ores containing a large proportion of such fines increase the propensity to hang which can only be cured (and then only in part) by a considerable reduction in the useful height of the charge, *i.e.*, the distance between the tuyeres and the upper surface of the charge. Unfortunately, this remedy accentuates bad distribution of the material due to the increased distance of free fall to the stockline.

Although it has been possible on occasions to use up to 65% of 0–10 mm. fines in the charge, it is possible and perhaps probable that it will be necessary to renounce the practice of incorporating systematically in the charge large quantities of constituents below 300μ. In the case of somewhat moist fine ore, this necessity will demand drying and preliminary screening of these fines, the final products being put on one side for agglomeration (not necessarily sintering).

Be that as it may, we consider that the heavy dust losses, which have been observed and which are of the order of those met with in normal blast-furnaces, can be substantially reduced by correcting the design of the furnace top.

Numerous modifications have, in the course of the trials, been made to the method of charging; separate layers of coke and ore have been tried in a variety of ways; mixed ore and coke has been used. It has been observed that charging in separate layers gives a better permeability than a mixture, but bearing in mind the bad conditions of mixing and the present distribution in the furnace, it is not possible to draw any conclusions.

It remains to observe that the use of 5·5-in. tuyeres with which the furnace was originally equipped gave poor results, probably because of excessive wall action. Insert rings of 3·1 in. were first used to get over this difficulty, and subsequently tuyeres of 2·4 in. diameter. The latter appear to give satisfaction. It is probable that the size of the tuyeres should be matched to the degree of enrichment of the blast, but in general it may be observed that in spite of its small diameter the low shaft furnace demands a critical entry velocity of the blast into the hearth.

Such is, in general terms, the condensed account of the low shaft furnace during the year of trials which has just come to an end.

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Thermodynamics of Carbon Dissolved in Iron Alloys

Part I: SOLUBILITY OF CARBON IN IRON–PHOSPHORUS, IRON–SILICON, AND IRON–MANGANESE MELTS

By E. T. Turkdogan, Ph.D., M.Met., and L. E. Leake

SYNOPSIS

The solubilities of carbon in iron–phosphorus melts were determined at 1290°, 1490°, and 1575° C. Phosphorus, like silicon, decreases the solubility of carbon in iron. An attempt has been made to generalize the effect of alloying elements on the carbon solubility in iron, and the factors which are responsible for these effects have been discussed. 1050

DURING recent years many investigators have made extensive studies of the physico-chemical aspects of iron–carbon liquid or solid solutions containing various alloying elements. Such solutions, *e.g.*, iron–silicon–carbon, iron–sulphur–carbon, iron–chromium–carbon, etc., deviate from ideal behaviour, so that a knowledge of the interactions between the solutes and between the solutes and iron is of great importance for the interpretation of reactions occurring during the smelting of iron ores and the refining of pig iron and steel.

Existing data indicate that a study of the thermodynamics of iron–carbon–alloy melts, such as arise in ironmaking, would be profitable. This paper deals mainly with an investigation of the influence of dissolved phosphorus on the solubility of graphite in molten iron at various temperatures.

EXPERIMENTS

Furnace

Melts were prepared in a vertical molybdenum-wound furnace, part of which is shown in section in Fig. 1. The ground-glass cone was removable for purposes of charging and sampling and was provided with an optical flat and a prism so that the reaction tube and its contents could readily be observed.

Temperature measurements were taken with a Pt/Pt–13% Rh thermocouple whose hot junction was located at the base of the crucible and was in close contact with it.

Furnace temperature was controlled by a Kent automatic controller. A separate control thermocouple was inserted into the furnace casing at a point close to the furnace tube and to a depth such that the position of the junction, which was held close to the winding insulation, corresponded to that of the hot zone within the furnace tube. Although the recorded temperature at this point was 150–200°C. below that inside the furnace, the period of operation of the control was effectively shortened. With this arrangement it was possible to maintain the temperature of the furnace contents to within ±1°C. of the desired value at temperatures of 1250–1600°C. The reaction crucibles were fashioned from graphite rod of high purity.

Materials

The charge, about 200 g. in weight, consisted of B.I.S.R.A. *AG* iron, containing 0·008% C, 0·002% Si, 0·005% Mn, 0·008% S, 0·001% P, 0·01% Ni, 0·001% Cr, 0·006% Cu, and 0·001% Al, to which was added sufficient iron–phosphorus alloy (containing about 10% P) to bring the phosphorus content of the total charge to the desired level.

Procedure

A graphite crucible was charged with an iron–phosphorus alloy of known composition and was

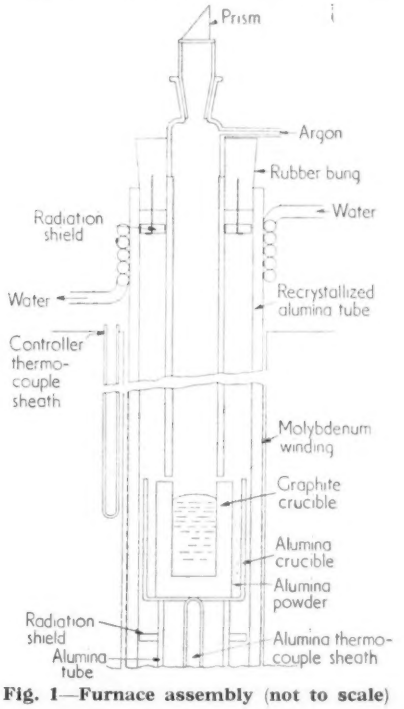

Fig. 1—Furnace assembly (not to scale)

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Dr. Turkdogan is the Head of, and Mr. Leake a member of, the Physical Chemistry Section of the Chemistry Department of the Association.

Table I

SOLUBILITY OF GRAPHITE IN IRON–PHOSPHORUS MELTS

No.	Temp., °C.	Weight-Percentage		Atom Fraction	
		P	C	P	C
G1	1290	4·18	3·07	0·066	0·124
G2	,,	2·99	3·68	0·046	0·148
G3	,,	1·47	4·16	0·023	0·166
H1	1490	4·15	3·51	0·065	0·140
H2	,,	2·97	4·14	0·046	0·164
H3	,,	1·47	4·63	0·022	0·183
I1	1575	4·18	3·67	0·065	0·147
I2	,,	2·96	4·37	0·045	0·172
I3	,,	1·48	4·87	0·023	0·190
J1	1505	0·00	5·25	0·000	0·205

supported in the reaction tube in which a flow of argon maintained an inert atmosphere.

When molten, the contents of the crucible were kept at a fixed temperature until equilibrium was attained. The melt was then sampled and analysed for carbon and phosphorus and this was repeated at three temperatures for each of three phosphorus levels.

Preliminary experiments were carried out to determine the time required for the melt to reach equilibrium after alteration had been made to the furnace temperature. Samples were taken at hourly intervals for 3 hr. and analysed for carbon. Though the results obtained indicated that saturation was reached within 1 hr. of the melt reaching its new temperature, it was decided in subsequent experiments to allow 2 hr. to elapse before sampling.

Sampling

Samples were withdrawn by lowering into the melt a silica tube of about 3-mm. bore. A partially evacuated bottle connected to the upper end of the silica tube *via* a stopcock provided a degree of suction which could be varied according to the weight of sample required. The stopcock was opened and, after a momentary pause, the silica tube with its charge was withdrawn from the furnace and plunged into a vessel of water. The sampling opération took about 10–15 sec. and samples procured in this way were rods of about 3 mm. dia. Traces of free graphite adhering to their surfaces were removed by rubbing with fine emery cloth. The specimens were then reduced to a granular state in a percussion mortar and analysed.

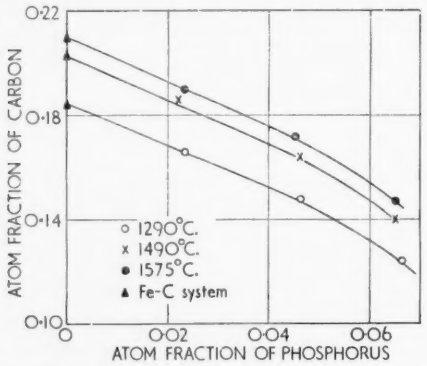

Fig. 2—Effect of phosphorus on solubility of graphite in molten iron at various temperatures

Analysis

The carbon contents of the samples were estimated by the combustion method, agreement between duplicates being within ± 0·01%. Analysis for phosphorus was carried out by the molybdate–magnesia method, results of duplicate experiments showing agreement to within ± 0·02%.

RESULTS

The experimental results are given in Table I. In Fig. 2 the solubility of carbon is plotted against the concentration of dissolved phosphorus at three temperatures in terms of atom fractions. The points lie on smooth curves which are extended to zero phosphorus content by utilizing the data on the solubility of carbon in pure-iron melts to which reference will be made in the discussion.

Schichtel and Piwowarsky[1] studied the effect of silicon, phosphorus, and nickel on the solubility of graphite in iron. They did not, however, publish their individual experimental results ; the points read from their carbon *vs.* phosphorus concentration curves indicate a carbon solubility for a given phosphorus concentration about 0·2% lower than that found in the present work. The carbon solubility in iron–silicon melts, interpolated from the curves of Schichtel and Piwowarsky, was also about 0·2% lower than those found by Chipman *et al.*[2]

DISCUSSION

Solubility of Carbon in Pure-Iron Melts

The solubility of carbon in pure iron (*i.e.*, equilibrium with graphite) has been well established. In Fig. 3, $\log N_C^C$ is plotted against the reciprocal of the absolute temperature, where N_C^C indicates the atom fraction of dissolved carbon in iron–carbon binary melts. There is good agreement between the results of various workers, particularly in the case of those obtained recently. The solubility of carbon in pure iron at 1505°C. has also been determined and the result is included in Fig. 3.

The relationship in Fig. 3 may be represented by the following linear equation :

$$\log N_C^C = -\frac{560}{T} - 0{\cdot}375 \quad \text{.....(1)}$$

This line passes through the binary eutectic point at $N_C^C = 0{\cdot}171$ (or 4·24% C) and 1153°C. This is the recognized austenite–graphite–liquid eutectic composition and temperature.[5]

Solubility of Carbon in Iron–Phosphorus Melts

To avoid possible confusion of symbols the following notation will be adopted : (i) in iron–carbon binary melts the atom fraction of carbon will be denoted by N_C^C and (ii) in iron–*X*–carbon melts, where *X* is a third dissolved element, *e.g.*, phosphorus, silicon, etc., the atom fractions will be indicated by N_C and N_X.

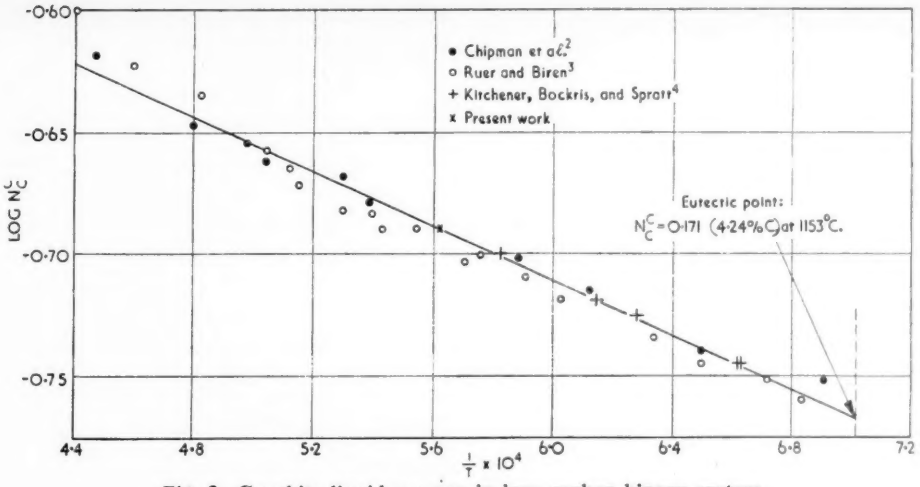

Fig. 3—Graphite liquidus curve in iron–carbon binary system

In Fig. 4, ΔN_C^P is plotted against the atom fraction of phosphorus. The term ΔN_C^P is the difference between the carbon saturation in iron–phosphorus–carbon ternary melts and that in iron–carbon binary melts, *i.e.*,

$$\Delta N_C^P = N_C - N_C^C \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where the values of N_C^C are calculated at any temperature from equation (1). The relationship in Fig. 4 appears to be independent of temperature, *i.e.*, when phosphorus is dissolved in carbon-saturated iron, the number of atoms of carbon displaced from solution per atom of phosphorus dissolved therein is not influenced by the temperature of the melt.

The following expression fits well the curve in Fig. 4 within the range 0·00–0·045 N_P :

$$\Delta N_C^P = -0{\cdot}84\ N_P \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Solubility of Carbon in Iron–Silicon Melts

As already pointed out, Chipman *et al.*[2] investigated the effect of silicon on the solubility of graphite in iron. Their results at 1290°, 1490°, 1600°, and 1690°C. have been treated in a manner similar to that described above, and in Fig. 5 ΔN_C^{Si} is plotted against the atom fraction of dissolved silicon ; the relationship is again independent of temperature. The curve is represented by :

$$\Delta N_C^{Si} = -0{\cdot}71\ N_{Si} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

for the range 0·00–0·08 N_{Si}.

Solubility of Carbon in Iron–Manganese Melts

Chipman *et al.* also showed that manganese increased the solubility of carbon in iron. From their results the values of ΔN_C^{Mn} and N_{Mn} have been calculated and are plotted in Fig. 6. The scatter of the points is much greater for this system than those already discussed. The iron–manganese–carbon melts used by these workers were contaminated with up to 1·0% of silicon. They corrected their carbon figures to allow for the lowering effect of silicon on the solubility of carbon in iron and any error in the method of correction may have caused the scatter of the points in the diagram. The following equation may be tentatively suggested for Fig. 6 :

$$\Delta N_C^{Mn} = 0{\cdot}1\ N_{Mn} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

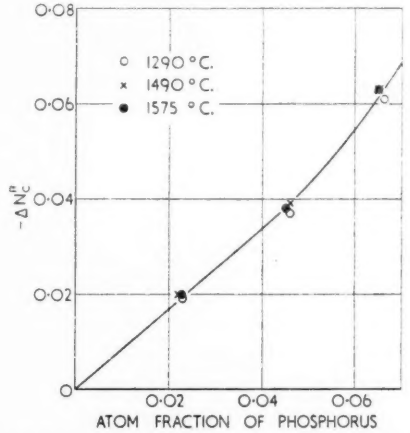

Fig. 4—Relationship between $-\Delta N_C^P$ and phosphorus concentration

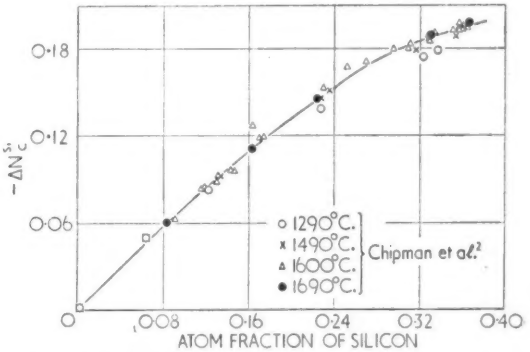

Fig. 5—Relationship between $-\Delta N_C^{Si}$ and silicon concentration

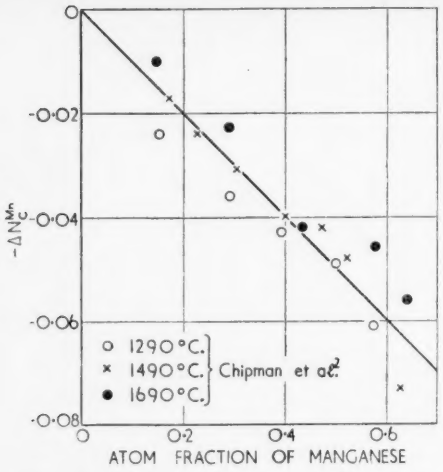

Fig.6—Relationship between $-\Delta N_C^{Mn}$ and manganese concentration

Theoretical Considerations

The relative effects of phosphorus, silicon, and manganese on the solubility of graphite in iron are compared in Fig. 7.

The influence of elements dissolved in iron–carbon melts is very similar to their effect on iron–nitrogen melts. The transition elements in the first long period, *i.e.*, vanadium, chromium, and manganese, increase the solubility of nitrogen in liquid iron at 1-atm. pressure of nitrogen, but silicon and carbon decrease it.[5] Richardson and Dennis[6] showed that chromium decreases the activity coefficient of carbon dissolved in iron, which indicates that chromium must increase the solubility of carbon in iron. The analogy between Fe–*X*–C and Fe–*X*–N systems is not surprising, because both carbon and nitrogen form interstitial solid and liquid solutions in iron and, generally speaking, interaction between dissolved element *X* and carbon, and between *X* and nitrogen, is similar because of the parallelism of the free energies of formation per mean gramme-atom of carbides and nitrides.[7]

However, although the tendency for compound formation between the solutes generally lowers their activities, interaction between the solvent (*i.e.*, iron) and solutes must be taken into account. For example, although the free energy of formation of silicon carbide, SiC, is more negative than that of manganese carbide, Mn_3C, the former decreases carbon solubility in iron, whilst the latter increases it. This is most probably the result of a much stronger interaction between iron and silicon atoms compared with that of iron with manganese atoms. This aspect has been discussed in detail by Richardson.[8]

Another factor likely to influence the solubility and activity of carbon dissolved in iron alloys is the nature and the magnitude of ionization of the atoms when dissolved in iron. It is known that a carbon atom dissolved in austenite loses electrons to the neighbouring iron atoms and becomes positively charged.[9–14] There is no doubt that a similar ionic structure (or partial ionic structure) will exist in the liquid state. As suggested by Kitchener, Bockris, and Spratt,[4] silicon and phosphorus dissolved in iron may also be positively charged. It would then follow that in iron–phosphorus–carbon and in iron–silicon–carbon solutions the solutes will repel one another because of their similar ionic charges ; this in turn will reduce the solubility and increase the activity coefficient of carbon.

It was postulated by Hume-Rothery, Mabbott, and Channell-Evans[15] that when the atomic diameters of solvent and solute differ by more than about 14–15% the size-factor is unfavourable and the miscibility range in solid solutions is limited. With a favourable size-factor the solid solution formed may have a much wider composition range. A similar hypothesis may also hold for the molten systems, but since the atomic diameters of solvent and solutes are unknown it is not possible to suggest any size-factor which could be related to the range of miscibility in the liquid state.

The structural differences between Fe–*X* and Fe–C systems may also cause the lowering effect of *X* on the solubility of carbon in iron. Kitchener, Bockris, and Spratt,[4] for example, have investigated the effect of sulphur ; this aspect has not been discussed here because experiments on the solubility of graphite in iron–sulphur melts are continuing.

CONCLUSIONS

The effect of an alloying element on the solubility of carbon in iron can best be represented by the plot of ΔN_C^X against N_X

where $\Delta N_C^X = N_C - N_C^C$

N_C^C = Atom fraction of carbon in carbon-saturated iron

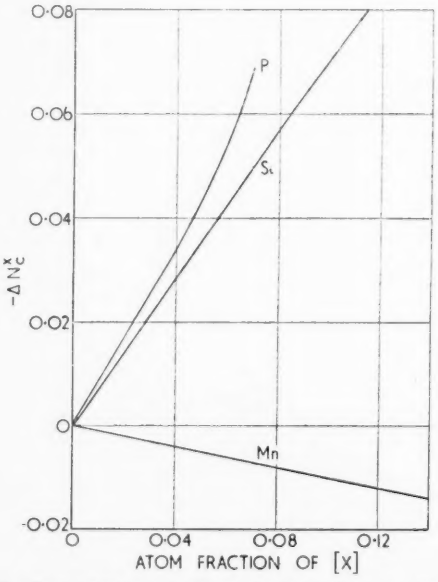

Fig. 7—Comparison of effects of phosphorus, silicon, and manganese on solubility of graphite in molten iron. This relationship is independent of temperature

N_C = Atom fraction of carbon in carbon-saturated iron–X alloy

N_X = Atom fraction of an alloying element X in iron–X–carbon melts.

For the iron–silicon–carbon melts :

$$\Delta N_C^{Si} = -0{\cdot}71\ N_{Si} \text{ when } N_{Si} < 0{\cdot}08.$$

For the iron–phosphorus–carbon melts :

$$\Delta N_C^{P} = -0{\cdot}84\ N_P \text{ when } N_P < 0{\cdot}045.$$

For the iron–manganese–carbon melts :

$$\Delta N_C^{Mn} = 0{\cdot}1\ N_{Mn}.$$

These functions are independent of temperature.

Possible causes of the observed effects of alloying elements on the solubility of graphite in iron are :

(i) Solute–solute and solute–solvent interactions
(ii) Ionization of atoms when dissolved in iron
(iii) The size-factor, which is determined by the radii of solvent and solute
(iv) The structural difference between iron–X and iron–carbon melts.

Acknowledgments

The authors wish to thank Dr. J. Pearson for helpful discussions and Mr. R. A. Hancock for determining the solubility of graphite in pure iron at 1505°C.

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Part II: INFLUENCE OF SILICON ON THE ACTIVITY COEFFICIENT OF CARBON DISSOLVED IN MOLTEN IRON

By E. T. Turkdogan, Ph.D., M.Met.

SYNOPSIS

The activity coefficient of carbon in iron–silicon–carbon melts has been calculated by an empirical method. The effect of silicon on the activity coefficient of carbon, γ_C^{Si}, is also a function of carbon concentration and independent of temperature. 1035

Knowledge of the interaction between elements dissolved in iron and between the elements and iron, as reflected in terms of activities or activity coefficients, is of importance for a clear understanding of the reactions taking place during the manufacture of iron and its alloys. In Part I of this series of papers,[1] it was shown experimentally that silicon and phosphorus lowered the solubility of carbon in molten iron. The present paper suggests a method by which the activity coefficient of carbon may be calculated for solutions of various concentrations of carbon and silicon.

Samarin and Shvartsman[2] have proposed the equation

$$\gamma_C = \frac{1}{1 - 5(N_C + N_{Si})} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where γ_C is the activity coefficient of carbon in iron–silicon–carbon melts with N_C and N_{Si} the atom fractions of carbon and silicon respectively. The value of γ_C was taken to be unity at infinite dilution of carbon. Equation (1) was a modification of a suggestion of Temkin and Shvartsman[3] that, because the number of sites available for carbon atoms in iron–carbon binary melts is one-fourth the number of iron atoms, the activity coefficient of carbon in a binary melt is given by

$$\gamma_C = \frac{1}{1 - 5N_C} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Samarin and Shvartsman concluded from experimental evidence that the sum of the atom fractions of carbon and silicon in carbon-saturated iron was constant and close to 0·20 and assumed that one unit cell could not simultaneously accommodate both a carbon and a silicon atom. Although these assumptions may be approximately true for a restricted temperature and composition range, general application of equations (1) and (2) to calculate γ_C will give erroneous results because the effect of temperature on the activity coefficient has not been taken into account, and the sum of the atom fractions of carbon and silicon, in carbon-saturated iron melts, depends on temperature and the silicon content of the solution.

Paper C/15/54 of the Chemistry Department of the British Iron and Steel Research Association, first received on 13th July, 1954, and in its final form on 23rd August, 1954.

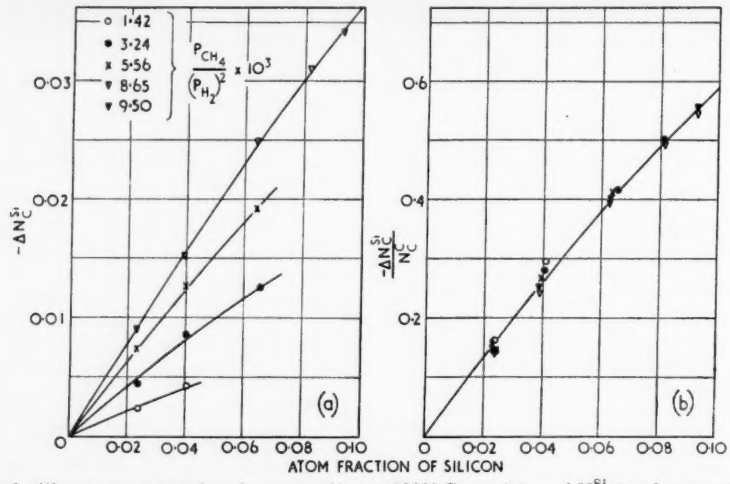

Fig. 1—Effect of silicon concentration in austenite at 1000° C. on (*a*) $-\Delta N_C^{Si}$ (various carbon potentials); (*b*) $-\Delta N_C^{Si}/N_C^C$ (relationship independent of carbon potential)

In other words, the assumption that $N_C + N_{Si} = 0{\cdot}20$ in carbon-saturated liquid iron is not justified. The work of Chipman *et al.*,[4] for example, shows that the sum of the carbon and silicon atom fractions in carbon-saturated melts increases from 0·185 to 0·273 as N_{Si} increases from 0·00 to 0·23 at 1290° C., and that $N_C + N_{Si}$ increases from 0·219 to 0·30 as N_{Si} increases from 0·00 to 0·23 at 1690° C. Clearly another approach is necessary.

ACTIVITY COEFFICIENT OF CARBON IN IRON–SILICON–CARBON TERNARY MELTS

It was stated by Richardson and Dennis[5] that an approximate solution law for carbon in γ-iron, postulated by Smith and Darken (*see* appendix to Smith's paper[6]), was in good agreement with the experimental results on iron–carbon melts between 1560° and 1760° C. In other words, a structural model proposed for iron–carbon alloys at 1000° C. also held good for iron–carbon melts. In view of this finding, the work of Smith[7] on the thermodynamics of carbon dissolved in iron–silicon–carbon alloys at 1000° C. may be made the basis for the computation of γ_C in iron–silicon–carbon melts.

Smith[6, 7] measured the activity of carbon in γ-iron–carbon and γ-iron–silicon–carbon alloys at 1000° C. by equilibrating the alloys with methane–hydrogen mixtures of known compositions. From his results the values of ΔN_C^{Si} and N_{Si} have been calculated and plotted in Fig. 1*a* at different carbon activities. The term ΔN_C^{Si} is the difference between the carbon content of an iron–carbon alloy and of an iron–silicon–carbon alloy, when the carbon activity of both systems is the same. That is

$$\Delta N_C^{Si} = N_C - N_C^C \quad \ldots\ldots(3)$$

when

$$N_C^C \cdot \gamma_C^C = N_C \cdot \gamma_C \quad \ldots\ldots(4)$$

where N_C^C, N_C, γ_C^C, and γ_C are the atom fractions and activity coefficients of carbon dissolved in iron–carbon and iron–silicon–carbon alloys, respectively. Figure 1*a* indicates that for a given silicon concentration the magnitude of carbon displaced by the dissolved silicon increases with the carbon activity of the solution.

In Fig. 1*b* the ratio $\Delta N_C^{Si}/N_C^C$ is plotted against the atom fraction of silicon. This relationship is independent of carbon activity, which varies from 0·05 to 1·0, corresponding to $p_{CH_4}/(p_{H_2})^2$ ratios of $1{\cdot}42 \times 10^{-3}$ and $9{\cdot}50 \times 10^{-3}$, respectively (β-graphite is chosen as the standard state for dissolved carbon).

It has been shown by Turkdogan and Leake[1] that for ternary melts ΔN_C^X at unit carbon activity, where X stands for silicon, phosphorus or manganese, was independent of temperature and a continuous function of the concentration of dissolved third element X, in graphite-saturated iron–X–carbon melts. For carbon-saturated iron–silicon–carbon melts the following relationship was found:

$$\Delta N_C^{Si} = -0{\cdot}71 N_{Si} \quad \ldots\ldots(5)$$

when $N_{Si} < 0{\cdot}08$, *i.e.*, $< 4{\cdot}2\%$ Si. Available data showed that the carbon content of iron saturated with respect to graphite may be represented by

$$\log N_C^C = -\frac{560}{T} - 0{\cdot}375 \quad \ldots\ldots(6)$$

Combination of equations (5) and (6) yields

$$\log\left(-\Delta N_C^{Si}/N_C^C\right) = \frac{560}{T} + \log N_{Si} + 0{\cdot}226 \quad \ldots\ldots(7)$$

As already illustrated (Fig. 1*b*) the value of $\Delta N_C^{Si}/N_C^C$ as a function of N_{Si} is independent of carbon activity in iron–silicon–carbon alloys at 1000° C.; it may now be assumed that equation (7), which is evaluated from experimental results at unit carbon activity, is also valid at lower carbon activities.

On the assumption therefore that equation (7) is also true at carbon activities less than unity, the activity coefficient of carbon in iron–silicon–carbon melts can be calculated at different temperatures and compositions by means of equations (3), (4), and (7) provided that the activity coefficient of carbon in

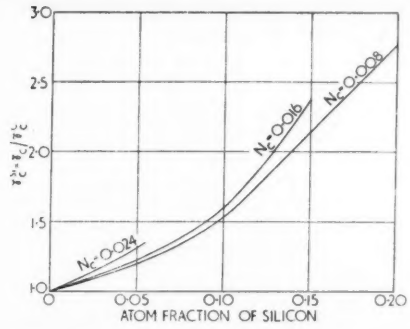

Fig. 2—Effect of composition on activity coefficient factor of carbon dissolved in iron–silicon–carbon melts (relationship independent of temperature)

iron–carbon binary melts is known. The required data are given by Richardson and Dennis,[5] who equilibrated iron–carbon melts with carbon-monoxide–carbon-dioxide mixtures of known compositions at various temperatures.

The calculation of γ_C in iron–silicon–carbon ternary melts can best be illustrated by the following example: assume an iron–carbon binary melt with N_C^C of 0·015 and, by means of equation (7), find the value of ΔN_C^{Si} for a ternary alloy with $N_{Si} = 0{\cdot}05$ at 1650° C.; it is $-0{\cdot}0027$. Therefore by equation (3) $N_C = 0{\cdot}015 - 0{\cdot}0027 = 0{\cdot}0123$. Since equation (7) holds only when the carbon potentials of both binary and ternary melts at these compositions and temperatures are the same, equation (4) can be applied, *i.e.*, $0{\cdot}015\gamma_C^C = 0{\cdot}0123\gamma_C$. The value of γ_C^C at 1650° C. and $N_C^C = 0{\cdot}015$ is calculated from the results of Richardson and Dennis[5] and found to be 0·672; it then follows that

$$\gamma_C = \frac{0{\cdot}015 \times 0{\cdot}672}{0{\cdot}0123} = 0{\cdot}819$$

i.e., $\gamma_C = 0{\cdot}819$ in an iron–silicon–carbon melt at 1650° C. containing 0·0123 and 0·05 atom fractions of carbon and silicon, respectively.

By this method γ_C has been calculated over a range of temperature and composition. When N_{Si} is greater than 0·08, equation (5) does not apply, and the curve in Part I relating ΔN_C^{Si} to N_{Si} should be employed.[1]

It has been found that γ_C is a function of carbon and silicon concentrations and temperature of the melt. On the other hand the ratio γ_C/γ_C^C, which may be designated by γ_C^{Si}, is independent of temperature, within the accuracy of computations based on an empirical relationship (*see* Fig. 1*b*).

In Fig. 2, carbon activity coefficient ratio γ_C^{Si} is plotted against the atom fractions of silicon for ranges of carbon atom fractions.

Chipman[8] also made an attempt to calculate the effect of silicon on the activity coefficient of carbon. According to this method of calculation the value of γ_C^{Si} at 1490° C. and 0·05 atom fraction of silicon is 1·23 and independent of carbon concentration, whilst the present calculations give (*see* Fig. 2) at $N_{Si} = 0{\cdot}05$ values of 1·16, 1·18, and 1·24 at 0·008, 0·016, and 0·024 atom fractions of carbon, respectively.

It was indicated above (Fig. 1*b*) that the value of

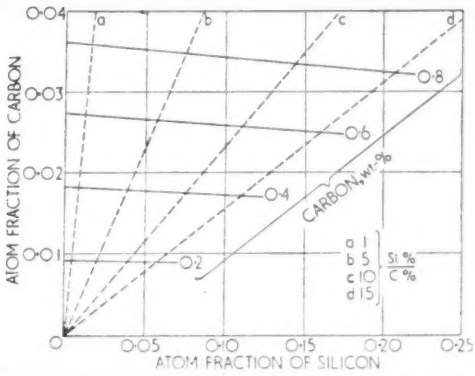

Fig. 3—Interconversion of atom fractions and weight-percentages in iron–silicon–carbon systems

$\Delta N_C^{Si}/N_C^C$ as a function of N_{Si} was independent of carbon activity and it was assumed that a similar condition held for iron–silicon–carbon melts. This is not, however, the case with iron–transition-element–carbon ternary systems. This is shown by the experimental results of Smith[7] on γ-iron–manganese–carbon alloys and Richardson and Dennis[9] on iron–chromium–carbon melts. In both cases the values of $\Delta N_C^X/N_C^C$ at given values of N_X (where N_X is Mn or Cr) increase with carbon activity.

Acknowledgments

The author wishes to thank Dr. J. Pearson and Dr. F. D. Richardson for their helpful comments.

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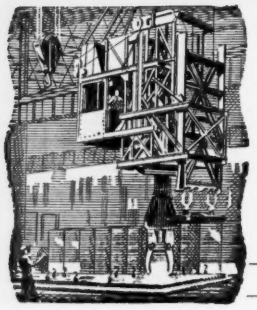
APPENDIX

Graphical Interconversion of Atom Fractions and Weight-Percentages

The application of the findings in this paper necessitates interconversion of atom fractions and weight-percentages and a graphical method may satisfactorily be used. In Fig. 3 the atom fraction of carbon is plotted against the atom fraction of silicon for ranges of carbon weight-percentage and ratios of Si%/C% in the iron–silicon–carbon ternary system. The relationships for iso-carbon percentage and iso-Si%/C% ratio are linear and the point of intersection of the lines gives the atom fractions of silicon and carbon corresponding to weight-percentages in the ternary system.



AFFILIATED LOCAL SOCIETIES

CLEVELAND INSTITUTION OF ENGINEERS

Some Starting and Operating Experiences at Abbey Melting Shop

By A. J. Kesterton, M.Eng., Ph.D., F.I.M.

SYNOPSIS

Mixer-bay operation is described, including the method of desulphurization, and mixer lining performance. The 200-ton furnace construction and refractory performance are explained in detail, as are stage layout and operation. Instrumentation and its use are described. An account is given of casting bay and mould bay operation, including the method of ingot traffic control. The handling of scrap, limestone, ore, etc., in the scrap and raw materials bays is explained, together with the system of stage traffic control. Slag and skull disposal are detailed. Finally, the use of oxygen for decarbonization is briefly described. 963

THE Abbey melting shop is an entirely new shop built between April, 1947, and April, 1951, to supply steel to the new Abbey strip mill. The latter is serviced in addition by the two older melting shops of Port Talbot and Margam, each with six furnaces, which are at present being enlarged from 75 to 100 tons capacity. The three melting shops receive hot metal from the three Margam blast-furnaces, two of 25 ft. 9 in. and one of 21 ft. 6 in. hearth dia. They produce at present about 18,500 tons of molten iron per week.

The three melting shops produce about 33,000 tons of ingots per week; the contribution made by the Abbey melting shop is 18,000–20,500 tons per week, depending mainly on the number of furnaces operating. The maximum shop output for seven furnaces operating was 20,695 tons in one week, as shown in Table I.

All the ingots are delivered to the stripper bay attached to the strip mill, and are then processed through the soaking pits, slabbing mill, slab yard (for inspection, deseaming, etc.), slab reheater furnaces, and strip mill.

The production of the strip mill is chiefly hot-rolled coil, the output of which is mainly divided for further processing between the cold-reduction mill at Abbey, where the product is largely high-grade sheet for the motor-car industry, and the cold-reduction and tin-plate lines at Trostre, where the product is exclusively tinplate. The strip mill also produces each week a small quantity of plate and heavy-gauge sheet; these are processed on finishing lines which are a continuation of the strip mill run-out table.

The product required from the Abbey melting shop thus consists of low-carbon, low-sulphur steel, mainly for the sheet trade. In fact, 90% of the steel required is to a specification of 0·07% max. of carbon, with sulphur varying between 0·025% and 0·04%, phosphorus generally less than 0·02% and more usually 0·015%, and with stringent specification limits on copper, nickel, and tin.

Table I

ABBEY MELTING SHOP O.H. FURNACES: RECORD WEEK 10.1.54

Furnace	No. of Charges	Ingot Production		Oil Consumption, gal./ton
		Tons	Cwt.	
G	13	2755	14	21·92
H	14	2963	19	19·12
J	15	3167	9	19·46
K	14	2967	7	20·81
L	14	2980	16	22·70
M	6	1249	4	22·93
N	8	1686	13	21·07
O	14	2923	12	21·37
Total	98	20,694	14	21·11

This paper was presented at a meeting of the Cleveland Institution of Engineers, held at the Cleveland Scientific and Technical Institution, Middlesbrough, on 1st March, 1954.

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MIXER BAY

The mixer bay is a northward extension of the furnace bay, and at present contains two 800-ton barrel-type inactive mixers.

The hot metal, which arrives from the blast-furnaces in 75-ton Kling ladles, is picked up from ground level by a single high-level 135-ton crane, and is poured into the mixer *via* a pouring-in opening situated in the top of the mixer. Before transfer to the mixer, however, it may be necessary to remove the desulphurizing slag resulting from the treatment of the metal with soda ash at the blast-furnaces. This is effected by taking the ladle over to stage level just north of the mixers, where the slag is raked off with wooden rabbles into a 400-cu.ft. slag ladle placed at ground level.

The analysis of the hot metal being produced at present is: Si, 0·5–0·7%; S, 0·03–0·06%; P, 0·6–0·8%; Mn, 1·0–1·25%. After desulphurization the sulphur content drops to about 0·03%.

The need for the low sulphur content in the hot metal arises from the sulphur specification required in the steel, which may be as low as 0·025%. If the sulphur in the hot metal rises to 0·10%, it is necessary, to meet the most stringent specifications, to carry out a second stage of desulphurization. This is effected in the mixer bay by emptying one of the Kling ladles into the mixer, after the normal slagging-off following one stage of desulphurization, and then throwing about 6 cwt. of soda ash into this empty ladle. The next full Kling ladle of metal with its slag is then poured into the ladle containing the soda ash. After the reaction has subsided, the slag is raked off in the usual way, and the metal is poured into the mixer.

The mixers are arranged at such a height and in such a position that when tilted they discharge metal through a pouring-out spout into 75-ton transfer ladles, held on carriages, which are on the same level as the furnace stage. There is a 150-ton weighbridge in the track below the pouring-out launder of each mixer, so that direct weighing of the metal as it is poured out is possible.

The track is laid from the mixer bay into the furnace bay along the back of the stage, from where the 75-ton transfer ladle may be picked up by the 135-ton overhead cranes in the furnace bay; the metal is poured into the O.H. furnace through one of the doors *via* a hot-metal chute.

The mixers are lined with magnesite bricks, except for the roof, which is Nettle firebrick. The linings to date have given the following performance :

Mixer	Campaign No.	Weeks in Operation	Metal Throughput, tons
North	1	53⅔	235,745
	2	29	268,756
South	1	30	232,130
	2	27	190,420

Little trouble has so far been experienced with the mixers. The wear and attack on the bricks proceeds for the most part along the joints between them. It is most pronounced on the side up which the metal rolls when the mixer is tilted for pouring, and there is a marked general attack on the jaws of the pouring out spout. The bottom, below the wash line, is not generally attacked to any marked degree, except directly under the pouring-in opening. Some trouble has been experienced, however, with metal penetrating the joints, probably higher up the mixer, and collecting and solidifying below the first, and even the second, course of magnesite bricks in the bottom of the furnace. Plates of metal up to 6 in. thick have been found in these locations, and have had to be removed. No doubt the rate of wear on the Abbey mixers has been accentuated by the continuous soda-ash treatment of the metal.

The relatively low total throughput of the last lining recorded was partly due to the fact that blast-furnace troubles were experienced during its life, resulting in a low weekly flow of metal, but also because, from this lining, a patch of bricks floated out of the inner course after about 4 months' operation. Fortunately, this was visible from the pouring-in opening, and it was possible to effect a temporary repair by emptying the mixer and firing a refractory mixture into the hole by means of a B.R.I. gun. The patch was slagged with a ladleful of O.H. slag and finally covered with dolomite. The mixer was then fired for a short period at the maximum attainable temperature (1450–1480°C.), the gas was taken off, and the temperature was set back for 2 hr. This form of patch with two renewals lasted seven weeks.

The temperature of the mixer is measured by means of thermocouples entering through the roof. The mixers are fired with cold coke-oven gas, the amount required depending on the throughput of hot metal, varying between 3000 and 10,000 cu.ft./hr., and averaging about 5000–7000 cu.ft./hr.

No trouble has been experienced mechanically with the mixers, but it has been found desirable to fix a device to the brakes on the motors to enable them to be mechanically released in the event of an electrical failure, which might occur with the mixer in the tilted position pouring metal. The mixers will return to the level position if the brakes are released.

FURNACES AND STAGE

There are at present eight fixed furnaces, each of 200 tons capacity. They are situated in blocks of four, each furnace being in a span of 110 ft. Between and at the ends of the blocks are rigid bays of 55 ft. span used for storage of such items as fettling machines and hot-metal chutes; there are also box benches, each holding four boxes, which contain the lime, ore, and scale used for feeding the furnace during refining. At every alternate gap between the furnaces there is a stand for four boxes. The remaining gaps between furnaces contain the narrow-gauge bogies which transfer the crushed ferro-manganese to the back of the stage, where there is a small weighbridge for weighing out the required additions to the 200-ton ladle.

Running along the back of the stage just in front of the control panels is the hot-metal track, along which the hot-metal locomotive conveys the hot-metal transfer ladles to the furnaces requiring metal.

The south end of the hot-metal track connects with

the track which runs down the ramp to the marshalling sidings. At present, the lime and dolomite containers are conveyed on their respective rolling stock to the south end of the hot-metal track, from whence the containers are picked up by the two 135-ton overhead cranes which span the furnace stage, and are conveyed along the shop to where they are required. The dolomite may be filled into the bins of the fettling machines or poured into the floor hoppers on the stage in front of each furnace. The lime containers are conveyed along the shop to fill the boxes on the stands between the furnaces, where they are in reach of the charging machines.

At the north, or mixer, end of the stage, a slag ladle is placed, into which the transfer ladles are tipped to remove the residual crust of slag, etc., left after pouring the metal. Removal of this slag prolongs the life of the ladle and maintains a good pouring lip.

Refractories for furnace repairs are at present brought up in wagons to the track in the charge-holding bay nearest to the stage. A proportion of the bricks arrive already palletized in trucks, the remainder being transferred to pallets at this point. When required, the pallets are transferred across the stage by means of fork trucks, and may be placed inside the door of a furnace for internal repairs, or lifted to a platform suspended at roof skewback height for roof repairs. In some cases the fork truck is used to convey the pallets round the furnace end to the back, where they may be lifted to a permanent gallery attached to the buckstays at roof skewback height.

Rubbish disposal is mainly *via* the slag chute immediately in front of the middle door of the furnace. A slag ladle is filled, moved underneath the furnace to the casting bay, and tipped into 60-ton air-dump wagons. It is also possible to throw the rubbish down the chute on to the ground between the elevated tracks of the slag ladle. A rocker shovel on tracks may then be used to back-load the rubbish into trucks berthed on the slag track in the casting bay. Rubbish from the slag pockets is also handled in this way.

New proposals are now being put into effect for the more expeditious handling of bricks and rubbish. Brick hoists being installed at three points along the shop will operate between the valve arch and the stage. Bricks will either arrive at the brick stores palletized or will be palletized there, and will then be conveyed by lorry to the valve arch. There are considerable spaces in the valve arch where the palletized bricks may be stocked for the anticipated furnace repairs. When required, the pallets will be moved by fork truck to the brick hoist and lifted to the stage, where they will arrive at the back of the stage between the hot-metal track and the charge-holding bay. From here, another fork truck will convey the pallets across the stage to the furnace.

A new method of rubbish disposal is also being put into effect, in which there will be three chutes located along the back of the stage in the same line, but at slightly different positions from the brick hoists. The chutes will lead down into bunkers in the valve arch, which will discharge into lorries of the tipping type, standing on one of the roads in the valve arch. The lorries will then travel to a rubbish recovery organization for salvage of metal and good bricks. Rubbish will be conveyed from the furnace across the stage to the rubbish chute by a system in which fairly small bins are placed in each door of the furnace and, after filling, are picked up by the fork trucks, conveyed across the stage, and tipped down the chute by a hydraulic mechanism on the fork truck.

Table II

INGOT OUTPUTS AND FUEL CONSUMPTIONS
12 Months Ending 30th May, 1953

Furnace	Av. Output tons/hr.	Av. Output (168-hr. Week)	Fuel-Oil Consumption, gal./ton
G	16·47	2767	20·57
H	16·42	2757	20·84
J	16·20	2721	21·61
K	16·10	2706	20·62
L	16·40	2755	21·78
M	16·87	2834	20·86
N	16·52	2775	21·30
O	16·35	2747	21·40
Record week (furnace N)	22·0	3762	15·48

FURNACE DATA

The performance of the furnaces is illustrated in Table II, which gives ingot outputs and fuel consumptions for the one-year period ending 30th May, 1953.

The hearth structure will be of some interest, since it is unusual for U.K. furnaces. The total thickness of the refractory from pan to the working surface of the hearth at the intersection of the centre-lines (in front of the taphole) is 42½ in.; this is thicker than normal. It consists of 1½-in. refractory concrete to cover the rivets, 7½-in. firebrick, 3-in. chrome-magnesite brick, 16½-in. magnesite brick, and 14-in. magnesite monolith. The latter consists of 4 in. rammed on the bottom, 7 in. along the banks, and the remainder fettled in at about 1640° C.

Before installing the first hearth, experiments were conducted with various magnesite–slag mixtures to determine which would be the best for making the hearth. It was finally decided to use a mixture containing 15% of crushed basic slag and 6% of tar for ramming, and one containing 12½% of basic slag and 2% of tar for sintering on the remainder. At the completion of the job the hearth was slagged in the usual way, and then 'set back' to harden before starting to charge.

The hearth is more heavily insulated than most furnaces, since it is 42½ in. thick, and up to 10½ in. of this consists of refractory concrete and firebrick. Other things being equal, this is noticeable during the refining stage, when the bath retains its high temperature with relatively low fuel inputs for the size of furnace. The bath will 'recover' rapidly from even heavy feeds of oxide, and, if it should become accidentally overheated, the oil must be cut off for

relatively long periods to effect the necessary cooling.

Whilst the degree of insulation is beneficial from the point of view of reducing fuel consumption, it would be a cause of additional fettling, particularly with the very low carbon steel being made at Abbey, if the monolith did not consist of magnesite. At Abbey there is fortunately a small quantity of magnesite available for fettling the bottoms. Therefore, although considerable trouble is experienced with the banks (which are fettled with dolomite) being washed out along the slag line, owing to the attack of the slags high in iron, the bottoms are retained in good order. It is considered, therefore, that the hearth design as installed, coupled with some magnesite fettling, gives a useful degree of insulation, without leading to excess fettling on low-carbon steel made in large 200-ton furnaces.

Fettling occupies about 75 min. at present. This includes the period during which the steel is running out of the furnace, since during this time fettling of the ends and front banks is carried out. Consumption of fettling material is about 66 lb. of dolomite + 11 lb. of magnesite per ingot ton.

An item of design which has proved to be of considerable benefit to the men working at the taphole is the provision of water-cooled tanks along the outside of the sloping back wall of the furnace. They are set off from the back wall about 8 in. and are not in actual contact with it. They require only a small trickle of water, need virtually no maintenance, and give very real protection from the heat radiated by the sloping back wall.

All five doors of the furnace are now lined with chemically bonded chrome-magnesite bricks instead of firebrick, as used originally. This has been found to improve the life from an average of about 9 days to about 25 days.

MAIN ROOF

In the original design, the main roof was all silica, in ringed construction, consisting of a 6-ft. wide drop section along the back skewback 18 in. thick, with 22-in. ribs at every fourth ring, the remainder of the roof being 15 in. thick with 18-in. ribs. Experience with the main roof in regard to refractory wear may be of some interest.

The roof suffers considerably from gouging attack just above the back skewback. This attack is most pronounced above the taphole, and is also severe close to the shoulders or wing walls, at the ends of the main roof. Between the taphole and the ends it is not normally quite so severe. The cutting varies in extent from about 4 ft. to 8 ft. up towards the crown from the back skewback.

In addition, another area subject to severe wear in the Abbey furnaces is the junction or knuckle between the main roof and the ramp roof over the port ends. Here two or three courses are rapidly attacked, usually right over the arch. Rapid wear of a localized nature occurs along the front skewback, in particular apparently over the doors, for a distance up from the skewback of about 2–3 ft.

Repairs to the original type of roof became necessary along the back skewback and at the knuckle or junction of main and ramp roofs after about seven weeks' operation, when the roof was patched in this area. This repair (which included a front lining when necessary) took about 12 hr. The roof would then run for a further four weeks, giving a total of about 11 weeks, by which time the attack along the front skewback was becoming a critical factor; the patch, of thinner bricks than the original, might again be wearing thin, and the area above the patch towards the crown would also be wearing out. After patching there was often trouble from roof movement. It was then necessary to take the furnace off for a new main roof, constituting part of the repairs then given to the furnace, which might be a general or mid-campaign repair.

The type of attack described, which is fairly severe, is probably closely connected with the design of the vessel and the port ends. To assist in modifying the design with a view to improving refractory life without affecting the fuel consumption adversely, a programme of work has started on a Perspex model of the furnace. The forward velocity and mixing contours have so far been worked out by B.I.S.R.A., and flow visualization with balsa dust has been carried out, but not photographed.

From this preliminary work, it is known that recirculation occurs over wide areas below the roof, but the backward recirculating velocities are not yet known. A vortex area is shown to be present immediately below the back skewback, which may be responsible for the excessive wear experienced in this location. A most interesting phenomenon has been demonstrated: at the outgoing end of the furnace, there is a flow of waste gas which sweeps up the back shoulder or wing wall to the roof, and then across the knuckle from back to front, to the downtake on the charging side of the furnace. This may account for the excessive wear on the knuckle, which is quite as severe as that experienced along the back skewback. Work will be carried out shortly on the effect of variation in design on the location and severity of wear, by the technique of particle deposition on the oiled inside surface of the model.

From the velocity and mixing curves so far obtained, calculations have been made of the fraction of fuel burned at four sections along the model, as shown in Table III. The fuel is quite evidently almost completely burnt at the middle door position.

In view of the heavy attack on the roof, various measures have been taken to improve the life of the refractories. In the main this has so far consisted

Table III

FRACTIONS OF FUEL BURNT

Section	Distance Along Model, in.	Actual Distance, ft.	Distance Along Furnace from Jet	Fraction of Fuel Burned	
				Gun Straight	Gun 4½° Towards Doors
1	5·1	10·2	1st door	0·53	0·675
2	9·6	19·0	2nd door	0·936	0·945
3	14·4	28·8	3rd door	0·984	0·974
4	19	38·0	4th door	0·999	0·996

chiefly in inserting into the roof at the vulnerable points refractories thought to be capable of a tougher performance.

The construction at present being mainly followed consists of a zebra section along the back skewback made up of alternate 6-in. rings of superduty silica and roof-quality chrome-magnesite. The zebra section extends 6 ft. up towards the crown, and is constructed in 15-in. bricks, the same thickness as the bulk of the main roof; *i.e.*, the actual drop of 3 in. along the back has been eliminated. Above the zebra section upwards towards the crown there is a further section of about 2 ft. of superduty silica brick. There is also a section 2 ft. wide of superduty silica brick along the front skewback. The remainder of the roof is in normal-quality silica bricks.

An unusual policy is also adopted in that, whereas the zebra section and the superduty silica section along the front skewback are of ringed construction, the remainder of the roof is bonded. It was found that, with a ringed construction right over, if heavy wear did develop on the zebra section or just above it, the strength of this section (presumably owing to the inclusion of the chrome-magnesite in its construction) was much weaker than one in 100% silica equivalently worn; considerable buckling tended to develop, which was difficult to control, even with a full set of roof battens. The bonded portion of the roof above the zebra transmits the load from the weakest to stronger sections.

The tendency for the chrome-magnesite rings to slip during the initial warming up, as a result of the differential expansion between the silica and the chrome-magnesite at low temperatures, has been taken care of by making additional expansion allowances in the silica rings of the zebra section.

The results of these changes in roof design are not as completely successful as had been expected. On the whole, heavy wear develops in precisely the same regions as before, but slightly less quickly; a patch along the back skewback is usually necessary after 8–9 weeks, although one or two roofs of this type did not require a patch along the back in a life of 12–13 weeks. In total, an extra 1 or 2 weeks life is obtained at about 12–13 weeks.

A very recent modification has been made to the actual design of the furnace throat, which has been widened out considerably by reducing the thickness of the shoulders or wing walls. The width at this section has been increased from 10 ft. 9 in. to 17 ft., on four furnaces so far. The results of this change are not yet established, but there has been no significant alteration in furnace performance, either in output or in fuel consumption; the severe localized attack on the roof just above the shoulder in the original design has been reduced slightly. On three furnaces the roof skewback along the back has recently been raised by 8–9 in. in an attempt to reduce the rate of wear. Table IV records roof life and performance to date.

On the back wall there is heavy wear along the slag line, owing to the continuous attack of the slags associated with low-carbon steel—*i.e.*, very high in iron oxide (up to 40% equivalent FeO)—at high temperature. This makes it advisable at most repairs to renew the back wall down to and including the slag line; the taphole brickwork is also renewed at each repair, since the wear on this area is also appreciable, and the risks are great if sound brickwork is not present in the taphole of a 200-ton furnace.

PORT DESIGN

The port design is of the conventional twin-uptake design with the oil gun carried forward into the furnace by means of an oil port or 'doghouse.' In addition there is a steep port-end ramp roof which, together with the pronounced angle of the walls of the shoulders or wing walls and the presence of a mixing space between the gun orifice and the throat, makes the design of the Venturi type; the aim is to direct the air towards the oil jet to promote rapid combustion, and to facilitate this by the injector effect of the Venturi design, the position of the jet orifice in relation to the throat being such as to secure this effect. The design is a true Venturi, the area of the throat being 92 sq. ft. (*i.e.*, less than the combined area of the air uptakes, which total 96 sq. ft.).

The distance of the jet orifice from the beginning of the bath is 5 ft. 10 in. In relation to the relative

Table IV
MAIN ROOF LIFE

Furnace	All-Silica			Part-Zebra		
	No. of Roofs	Av. Casts per Roof	Max. Casts per Roof	No. of Roofs	Av. Casts per Roof	Max. Casts per Roof
G	8	136	162	...	...	...
H	7	112	148	1	152	152
J	5	158	195	1 (Silcrete)	161	161
K	4	138	156	3	138	162
L	5	124	152	1	162	162
M	2	151	183	1	176	176
N	1	173	178	1	142	142
O	1	144	144	1	152	152
Av. all furnaces	33	136	165	9	151	158

speed of combustion promoted by the port end design, this dimension is of considerable importance from the point of view of fuel consumption. At Abbey it is thought that a partial explanation of the good fuel consumptions is that flame development is nicely adjusted close to the optimum before impingement on the bath.

If the Abbey port design and the relative proximity of the jet orifice to the bath do not ensure that combustion is as far forward when the flame reaches the beginning of the hearth as in some designs, such as the single uptake, it is nevertheless felt that the advantage of the optimum amount of luminous flame over the bath is obtained; in addition, the bath is long enough to prevent losses either by unburnt fuel passing out of the furnace, or by the length of hearth which remains after complete combustion being inadequate to permit optimum transfer of heat to the vessel.

In this connection, the relatively high value of the length/breadth (L/B) ratio of the Abbey hearth design may be significant. The length of the hearth inside the monolith is 51 ft. 8 in. and the breadth is 16 ft., giving an L/B ratio of 3·23. The more usual ratio in U.K. furnaces is between 2·75 and 3·00.

SLAG POCKETS

There is a single slag pocket at each end of the furnace. The slag pocket and fantail walls are of considerable surface area and no doubt play a notable part in the heat exchange; they are well insulated and steel-plated, thus minimizing losses due to radiation and air infiltration. The minimum refractory thickness consists of 4½-in. insulation, and 22½-in. silica brickwork.

The main slag-pocket arch, which has a span of 18 ft. 9 in. and is 6 ft. wide, is built in silica, and, although fairly durable, suffers considerable wasting of the sides and arch. Frequent repairs are necessary, although the total life of the arch will probably be about 2 years, after which complete rebuilding will be necessary. This is a major effort, involving not only the arch itself, but also the sloping uptakes which are skewbacked off it.

The fantail arches and pier are also a source of trouble of a continuous nature. They are built in silica, and are subject, by virtue of their situation, to considerable wear by erosion and slag attack; the fantail pier in particular is exposed to this high-temperature attack on both sides simultaneously. Repairs are sometimes required after 12–13 weeks, and are almost invariably necessary after 24–26 weeks. Collapses have occurred in mid-run, to the detriment of output and furnace scheduling.

Mitigation of the latter trouble has been effected by alterations to the design. The fantail pier, previously a vertical pillar 3 ft. wide, has been constructed with considerable sideways batter. The vertical wall of the uptakes above the fantail arches has been partially supported on steel channels to take the weight off the arches. The sloping uptake, which was formerly skewbacked off the uptake wall, has been provided with an independent skewback from the steelwork. Originally, therefore, should the fantail arches fail, there was danger that a collapse of the vertical uptake and the sloping uptake would follow. This risk has been reduced to one of minor proportions.

In determining the design of the new furnaces now being built for the expansion of the shop, it may be mentioned in parenthesis that it is proposed to try and eliminate some of the troubles just enumerated by the following measures. The fantail arches will be replaced by a single suspended arch in high-alumina firebrick. One of the main advantages of this will be the elimination of the fantail pier, which is exposed on both sides. The main slag-pocket arch, which at present contains a vast mass of brickwork, will be greatly reduced in size by lifting it much higher. The uptakes on the inner sides of the slag pockets will be brought down to suspended arches in high-alumina firebrick, of the same type as that replacing the sprung fantail arches.

SLAG REMOVAL

Slag requires to be removed after about 24–26 weeks. After this time it is about 5 ft. thick and may weigh up to 100 tons. Obviously, this represents a major problem. Removal by the conventional methods of pneumatic pick, jacks, etc., is too slow, and something else had to be devised.

The method at present used involves the use of a steel slab 25 ft. × 5 ft. 6 in. × 7½ in., rolled from a 20-ton ingot. This is introduced into the slag pocket with about 4 ft. projecting through the wicket wall into the casting bay. The portion inside the slag pocket is protected with about 4½ in. of firebrick. A square hole cut out of the far end enables the slag to fill this and thus provide a good grip. A massive lifting eye is attached to the portion of the slab insert projecting outside. A specially constructed beam is suspended from the hooks of the 300-ton crane hoist. From the centre of this beam a very heavy anchor chain hangs, to which is attached a massive shackle. The latter is coupled to the eye of the slab and the main hoist of the crane used to lift the slag mass. There is no difficulty in lifting and freeing the slag lump in one mass, although it occasionally breaks up into several large lumps which have to be removed individually from the pocket.

If the slag lifts in one piece, the problem is to withdraw it horizontally from the pocket. A horizontal pull is obtained by attaching a stout wire rope to the eye of the slab, and passing this under the 340-ton test weight to the 60-ton auxiliary hoist of the casting-bay crane. By judicious simultaneous use of the 300-ton and 60-ton hoists of the casting-bay crane the slag is withdrawn in one lump.

REGENERATORS

There are twin regenerators of equal size and checker capacity at each end of the furnace. The checker volume in each is 5270 cu. ft., making a total of 10,540 cu. ft. at each end of the furnace. This is quite a generous figure and must in part account for the good fuel consumptions.

Additionally, the side walls are well insulated with 4½ in. of Economite-type brick and lined with 1 ft. 10½ in. of firebrick, and the outside is steel-plated. The roofs consist of firebrick 13½ in. thick,

with 3 in. of vermiculite plastic insulation sprayed on.

Two types of checker filling have been used; one is the Danforth–Peterson, with 7½ in. × 7½ in. openings, and the other is a chimney checker with 9 in. × 9 in. openings. No significant difference can be detected between the two types from the point of view of output and fuel consumption, but the chimney checker is easier to clean. The top 10–12 courses require renewal after 9–12 months.

The regenerator chambers for the new furnaces will have the dividing wall of the present design reduced in thickness from 36 to 18 in., and the top will be cut short at the level of the checkers. This will give some increase (approx. 5%) in checker volume. The roof will become flat and suspended in Scotch firebrick quality bricks.

FLUES AND REVERSAL VALVES

All flues are of generous dimensions, those leading to each regenerator being 5 ft. wide × 7 ft. high to the top of the arch. The main collector flue to boiler and stack is 7 ft. wide × 7 ft. high to the top of the arch. All flues are encased in concrete and are well drained. Inside the concrete, the flues are lined with 4½ in. of insulating brick and 13½ in. of firebrick. The air reversal valves are of the straight-through type. The total resistance in the evacuating system is low, and the furnace normally operates with about 0·5 in. of suction measured in the main flue just before the boiler.

BOILERS

Each furnace is fitted with a forced-circulation waste-heat boiler. These are water-tube boilers with the tubes closely packed, the water being circulated through the tubes by special pumps. Special measures have to be taken to ensure that the tubes are kept as clean as possible. There are cleaning doors located vertically up both sides of the boiler, through which the tubes are blown with compressed-air lances once per shift.

With the waste gases from the Abbey furnaces the boilers are averaging about 9000 lb. of steam per hr. at a pressure of 195 lb./sq. in. and a temperature of 650° F. (343° C.). The inlet temperature of the flue gases averages about 1000° F. (538° C.) and the exit temperature about 540° F. (282° C.).

INSTRUMENTATION

The Abbey furnaces are fully instrumented, and there is no doubt that this has contributed in major degree to the performance obtained. The oil is metered by means of a Tylormeter, which drives a Transometer at a speed directly proportional to the rate of oil flow. The Transometer translates the speed signal from the Tylormeter into an air impulse, the pressure of which is proportional to the oil flow. The air impulse is used to operate on one side of each of three diaphragm heads of a control unit.

The first is that which stabilizes the oil flow at the selected level, in the range 0–600 gal./hr. The second is used to control air/oil ratio to the selected level. Selection may be made within the range 1250–3550 cu. ft. of air per gal. of oil. This control unit will maintain the selected air/oil ratio whatever the oil flow. The third diaphragm is used to control the atomizing steam/oil ratio. The control unit is also used to maintain the furnace pressure (as measured at the crown of the roof) constant at any selected level.

On four furnaces the roof temperature is measured by selenium-cell partial-radiation heads sighted on two points of the roof about 10 ft. from the knuckle at each end. The signals are amplified by D.C. amplifiers and transmitted to temperature indicators, one for each end of the furnace. There is also a maximum temperature channel selector, which selects the impulse from the highest-reading radiation head and indicates this on one large temperature-reading dial and also records it on a time chart.

On the remaining four furnaces the radiation heads are rare-metal thermopiles of the total-radiation type. The impulse from these is amplified electronically and measured potentiometrically. There are two large-scale indicating recorders on the panel, one for each end of the furnace.

Other important instrumentation includes radiation pyrometers sighted on the tops of the checkers (one for each of the four chambers), which record on two twin-point recorders. The outer checker chambers at each end are coupled to one of the twin-point recorders, and the inner chambers are coupled to the other. The trace produced on each recorder is of the crossing diamond type, which is found to be the most suitable type for giving the first hand an indication of whether the checker temperatures at each end are in balance.

Additionally, the oil, steam, and air flow rates are indicated and recorded on Foxboro-type instruments. The steam and oil pressures on the lines just before the atomizers at each end of the furnace are indicated on two-point indicators. The furnace roof pressure and the suctions before and after the boiler are also indicated and recorded on Foxboro instruments.

On each panel there is an electrically operated time clock and an indicator which registers the reading of the bath-temperature pyrometer. On one furnace only (in the middle of the shop) there is a twelve-point instrument for recording the bath temperatures on all the furnaces. The source of the trace on this instrument is easily deducible, since it is numbered from 1 to 12 according to the originating furnace.

The furnace may be reversed either manually or automatically. Before reversing it is necessary to operate a freezing control switch, which fixes the positions of the oil-flow control valve, the air-flow control louvres, and the draught-control louvres. If this is not done the oil-flow control valve would open fully, the air-flow louvres would close fully, and the draught-control louvres would also close fully during reversal. Obviously this would lead to the production of black smoke in large quantities, caused by unburnt oil.

Automatic reversal in relation to the Abbey furnaces means that the operation of the master reversing switch by the melter initiates the reversal sequence, which is then carried out to completion automatically, *via* a sequence controller, which impulses the relays actuating the electrically operated

control valves in the oil- and steam-flow lines at each end of the furnace and the motors operating the air reversal dampers.

On the new furnaces now being constructed, automatic reversal of the furnace will be carried a stage further in the sense that reversal will initiate itself on a time basis. The melter will be able to select the length of the time interval between reversals; he may make this the same for both ends, or he may choose to keep the fuel for a longer period on one end than the other, should the checker temperatures not be symmetrical.

The air/oil ratio control is set at a figure which will give an excess air of about 10–12% during charging and until the addition of the hot metal. At this point, to make use of the carbon monoxide being given off and to use it as a fuel, the air/oil ratio is increased to give about 25% of excess air. During the period of considerable gas evolution following the hot-metal addition, the actual oil flow may be considerably lowered, and can often be reduced to as low as 150 gal./hr. Occasionally it may even have to be taken off altogether, the gas from the reaction being adequate (if given sufficient air for combustion) to maintain the maximum permissible roof temperature. Paradoxically, the roof has sometimes been burnt with no oil on the furnace. The roof is operated hard up to the maximum permitted temperature (1650° C.).

During refining the air/oil ratio is maintained at the figure giving 25% excess air, calculated on the oil input, even though at that time the gas evolution does not warrant this additional air to burn it. The higher excess air is maintained in the hope of preserving the roof from a high rate of wear.

The furnace roof pressure is measured by a differential-type system and is kept constant by automatic control. The pressure required varies a little from furnace to furnace, and is about 0·10 in. W.G. There is a compensating leg in the circuit which makes allowance for the buoyancy in the measuring leg due to the temperature.

The steam/oil ratio control has not been found successful as a means of controlling the flame to a fixed length. If a good flame length (say, to the middle door) is produced at high oil-flow rates of the order of 500 gal./hr., with an oil/steam ratio of 4½ lb. of steam per gal. of oil, the same flame length is not obtained with 4½ lb. of steam per gal. of oil, if the oil-flow rate is reduced to 200 gal./hr. The flame is much longer and more smoky under such circumstances, and it is found necessary to use a much higher steam ratio to shorten the flame to the middle door.

A possible explanation for this is that at the high rates of oil flow, the use of 4½ lb. of steam per gal. of oil for atomizing, requires the steam to be at a pressure of, say, 125 lb./sq. in. At low flows of 200 gal./hr. a steam consumption of 4½ lb. per gal. of oil will be provided by a steam pressure of about 50 lb./sq. in. This great difference in the energy provided by the same relative quantity of steam accounts for the difference in the length of the flame.

Therefore, to produce a constant flame length with variable oil flows, the quantity of atomizing steam measured in lb. of steam per gal. of oil has to be varied as the oil flow varies. A control based on a constant weight of steam per gal. of oil therefore becomes ineffective.

CASTING BAY

The 200-ton casting ladle rests on a stand below the launder for tapping. One 400-cu. ft. slag ladle will not hold the total slag which runs off through the taphole during casting. It is therefore the practice to hold one slag ladle by means of the 60-ton hoist of the casting-bay crane under the slag chute of the 200-ton ladle, whilst a second slag ladle is placed on the ground beneath the slag chute. The slag ladle held by the crane is filled first, and taken away, the remaining slag falling into the slag ladle standing on the ground.

At the end of the tap, the 20-ton hoist of the casting crane is used to lift the launder away. There is no short launder, the joint between launder and furnace being very close to the furnace. This launder is held by the crane during teeming, although it is sometimes lowered to ground level during the filling of a mould, when the crane is stationary.

The absence of a short launder has been found to be of great assistance to the second hands in the maintenance and operation of the taphole. It has been of particular value when the need has arisen to cut down the taphole to drain a hole in the bottom. The fact that a short launder has not to be removed on these occasions is a great help in expediting the job.

The 200-ton ladle design has been successful, and hardly any alteration, even in detail, has been made. One minor improvement found to be very useful has been the provision of facilities for fitting a sand plate below the nozzle. With this in position, the orifice of the nozzle is filled with sand before the stopper is set up. This device has completely eliminated the occurrence of a leaking stopper while the ladle is being filled on the stand. The sand plate is removed when the ladle is standing at the teeming stage before starting to pour.

The ladle lining life varies between 7 and 11 heats, with an average of about 9. This is considered to be good practice on the type of steel being made (very low-carbon), which is associated with high temperatures and very corrosive slags, high in iron oxide.

The stopper-making and drying installation has been a successful item of plant. This is located half-way along the casting bay in the rigid bay between the two groups of four furnaces. The used stoppers are carried by means of the casting-bay crane from the ladle to a receiving bench, where the old sleeves are knocked off. The rods are then pushed on to a roller path, which feeds them through a press in which they are cold-straightened. The straightened rods run on to another bench, where they are stocked before being made up.

The rods are very carefully made up into stoppers, using screwed-on graphite stopper ends. The sleeves are jointed with S'airset, and sand is used to fill the gap between the rod and the sleeves. A steel spring is placed on the top sleeve and held in position by a washer and nut. The function of the spring is to take up the expansion of the sleeves, whilst holding

them firmly in contact with each other, to prevent penetration of metal between the joints which might cut the rod and so produce a 'flier.'

The stopper is then lifted by means of a small hoist on to an endless-chain conveyor which carries the stopper vertically through the drying oven. In this drying oven the stoppers pass through a chamber heated to about 150° F. (66° C.) by means of a current of heated air entering through ports in the floor of the oven. This current of air passes upwards round the stoppers, and is withdrawn at the top of the oven by means of a recirculating fan, which returns it to the ports in the base of the oven. To maintain the correct temperature, there is a separate combustion chamber in which is burnt a small quantity of coke-oven gas. The hot gas thus produced is added to the recirculating air just ahead of the fan.

The ingots are all car-cast. The moulds vary in size from 7 to 20 tons, and are both open-top and bottle-top. The bottle-top ingot (mainly in the 15-ton size) is used almost exclusively for tinplate. Using this mould the ingot to slab yield is about 4% greater than for open-top moulds, and the segregation is less. The possibility of blowholes close to the ingot surface is greater, but, by not adding the aluminium required to make the steel rise until the mould is nearly full, the initial rim is formed as for normal rimming steel and is therefore solid, although it is very much thinner.

Each ingot car will carry a load of about 150 tons. They are normally set up with either two 20-ton bottle-top, two 16-ton open-top, two 14-ton open-top, three 15-ton bottle-top, three 12-ton open-top, four 10-ton open-top, or four 7-ton open-top moulds.

The control of the movement of trains of ingots between the casting bays of the three melting shops, the stripper bay, the soaking-pit bay, the mould bay, and the cooling tracks is vested in an ingot-traffic controller. He is situated in the stripper bay and is housed in an office about 20 ft. above ground level at one end of the bay. Here he has an excellent view of all the tracks in the stripper bay and the soaking-pit bay, where the greatest number of short-length movements of the ingot trains takes place. His duty is to plot on a special chart all movements of each train of ingots. The chart therefore keeps him abreast continuously of the whole panorama of ingot and mould movement; on the basis of this exact knowledge of the current position, he plans the forward movement of every train of moulds and instructs the three 660-h.p. Diesel-electric locomotives to this effect by radio-telephone.

The information which he receives from the bays not under his visual observation to enable him to operate as described includes a forecast from each melting shop once per shift of the anticipated tapping times and of the time of commencing to teem each cast. From the mould bay he receives the time when each cast has been prepared. From this are deducible the times when empty trains of moulds should be moved into the melting shop for tapping, and the times when the full casts will be ready for removal to the stripper bay. The system has worked very well on a large site to control the expeditious movement of up to 33,500 tons of ingots in one week.

MOULD BAY

There are four stages in the mould bay, and three 25-ton cranes for preparing the moulds for casting. The casts of dirty moulds on arrival from the cooling tracks just outside the mould bay are treated as follows. Each mould is first scraped clean both on top and inside to remove splashes and scruff. Cleaning of the inside of the bottle-top moulds is necessarily limited, but the tops are thoroughly cleaned. Each mould is then lifted off the ingot car by means of a special bridle hung from the crane, which enables the mould-bay men to brush the bottom plate and place pad plates and a splash can in position. The mould is then replaced carefully. Following this, a mould wash of graphite is given by means of an injector-type spray gun which sucks up the graphite–water mixture from a tank in which it is kept well mixed by a compressed-air jet.

At present mould bottoms are in use in which there is a brick insert. This has practically eliminated bottom stickers, which were previously troublesome, and has doubled the life of the bottom plate. However, it is now somewhat suspect, because it may inhibit the initiation of a good rimming action, since it will prevent rapid initial solidification on the bottom, on which a vigorous gas evolution depends. Reversion to the plain cast-iron or reduced brick-insert type is planned for this reason, to prevent formation of blowholes near the skin, which produce skin laminations in the sheets.

The splash cans are made in the mould bay from defective sheet by the mould-bay men, who roll them in an electrically driven three-roller plate-bending machine. One, two, or three sheets are rolled together, depending on their thickness, to give a total thickness of about $\frac{1}{8}$ in. The diameter of the splash can is about 20 in. and its height 22 in. Apart from the prevention of splash adhering to the sides of the mould wall (and hence of the ingot), the cans have had a very good effect in preventing attack on and excessive gouging of the lower parts of the mould walls resulting from the high-velocity horizontal throw of the metal on striking the bottom, which used to shorten the mould lives very considerably.

Mould life is very good considering the type of steel made and the fact that most of the moulds are of a pronounced slab shape, which is known to shorten life. The average mould consumption at present is 28 lb. per ton of ingots. This corresponds to lives ranging between 70 and 150, and averaging about 90 for most moulds.

SCRAP BAY AND SCRAP HANDLING

The scrap bay is 770 ft. long and is provided with four trimming platforms against each of which about 25 scrap-box bogies may be berthed. The top of the trimming platforms is flush with the tops of the scrap boxes, thus giving the trimmers excellent coverage of the boxes, which enables them to work efficiently in trimming the scrap in the short period between magnet journeys.

There are now four 10-ton magnet cranes with 65-in. magnets. The plant actually started and operated for over two years with only three magnet

cranes. During this period there were up to seven furnaces operating, with an ingot output rising to 19,700 tons of ingots in one week; the three magnets handled up to a combined total of 12,226 tons/week of scrap, pig, moulds, and skull. The best turnover in one day was 1993 tons.

A good deal of the scrap returned from the mill was and is of very poor quality from the point of view of rapid loading, consisting of rejected sheets and sheet cobbles which are very thin and light in weight; it has only been possible to burn these to box size, but not to upgrade them otherwise in density. The whole problem of scrap preparation is now being actively developed, however, as described later in the paper.

The average weight achieved per box, taking all types into consideration, is about 20 cwt.; boxes are of 40 cu. ft. capacity. The wagons containing the scrap are berthed on two tracks running the full length of the scrap bay immediately behind the trimming platforms. The track level has been lowered to ensure that the top of the trucks is approximately on the same level as the top of the scrap boxes. The magnet haul is therefore short in the cross-travel direction and involves almost no hoisting. Rapid scrap handling has thereby been greatly facilitated.

Beyond the wagon tracks, and running almost the full length of the building, is a scrap bunker 760 ft. long × 18 ft. wide × 18 ft. deep. Depending on the scrap density, it will hold between 6000 and 12,000 tons of scrap. This does not constitute the total scrap stock held by the melting shops, since large ground stocks are held outside the building alongside the melting-shop ramp; it constitutes, however, an excellent buffer to cover such contingencies as yard traffic difficulties (*e.g.*, derailments, loco breakdowns, and fog), temporary pressure of work elsewhere, and shortages of scrap loaded in wagons, with which the outside scrap-loading facilities cannot cope. In reverse, the scrap-bay magnets can put scrap to stock to relieve wagon standages caused by gluts arising from simultaneous over-delivery by ship and rail.

The organization for control of the movement of the bogies between scrap bay, stock bay, charge-holding bay, and furnace stage may be of some interest. There are two small (165-h.p.) Diesel engines on the stage, which are used for moving the bogies. The control of the movement is under a single stage-traffic controller who is located in an office on the top of the scrap foreman's office half-way along the scrap bay. From here he can see the whole of the scrap bay, the stock bay, the bulk of the charge-holding tracks, and the south end of the furnace stage, where the empty bogies are ejected from the charging track in front of the furnaces.

In a manner similar to the ingot-traffic controller, the stage-traffic controller charts the movement of all the bogies throughout the whole of their circulation. At all times, therefore, the position and condition of every bogie is known; *i.e.*, whether loaded or not, and if so with what material. With this information before him the stage-traffic controller plans the forward movement of all the bogies; he issues instructions to the Diesel locos by radio or by the public address system, whichever is more convenient.

He works in close conjunction with a charge controller located on the stage, whose duty is to haul on the loaded trains from the turnouts leading in from the charge-holding bay, as required by the furnaces, using the charging machines for this purpose, and split the train on the charging track in front of the furnaces to give each furnace the correct amount of material at the right time for the exact charge required.

In the system used at Abbey the full bogies are generally brought in *via* No. 1 turnout at the north end, allocated and charged to the necessary furnaces, and then passed along the full length of the charging track in front of the furnaces to be thrown out at the south turnout (No. 3), which does not connect into the running track like the other turnouts. This arrangement ensures that the ejection of empties does not foul the running track in the charge-holding bay along which the full bogies are passing from the weighbridge to No. 1 turnout.

STOCK BAY

In this bay are stocked and handled limestone, ore, scale, fluorspar, ferro-silicon, and ferro-manganese. There are two high-level tracks running over the tops of in-line bunkers. Hopper wagons containing limestone, ore, scale, or fluorspar are discharged through the tracks into the bunkers.

The bunkers are divided up to give the following stocking capacities; limestone 1200 tons, ore 1500 tons, scale 400 tons, fluorspar 80 tons.

Loading into the boxes on the bogies on one of the tracks over the bunkers is effected by means of two overhead cranes which manipulate 40-cu. ft. capacity grabs. The cranes have 10-ton auxiliary and main hoists. By lowering the mouth of the grab until it is inside the box and opening slowly, it is possible to prevent much of the material from falling between the boxes on to the car top. Should this occur, the tare weight of the empty bogie would go up, and since the bogies are not weighed empty but are assumed to have an average weight which is calculated weekly, excessive spillage of this type has either to be avoided or cleaned up on occurrence, otherwise inaccurate material weights would be obtained. It is also sometimes necessary to lift off all the boxes and sweep the car tops clean.

Ferro-manganese and ferro-silicon are crushed at one end of the bay. The wagons are berthed on the high-level track, and unloaded by hand through the crusher, which discharges into a bunker; the crushed material is led from the bunker by means of a vibrator-type chute into a portable bin holding about 8 tons of crushed ferro-manganese. The portable bin is lifted by the crane on to one of the scrap bogies usually left empty next to the loco, and thence conveyed to the stage. Here it is lifted off by the 135-ton hot-metal crane and placed on a small bogie on rails between every alternate furnace. This is pushed through to the casting-bay side of the stage, where the alloys are weighed on a small weighing machine and then transferred to the back of the

furnace for throwing by hand into the 200-ton casting ladle.

In the stock bay it has been found that the ordinary clam-type grab with single-reeve purchase is not a good performer when picking up lump limestone. The jaws do not penetrate far into the limestone, and tend to ride out as they are closed. The result is that only 25–40% of the capacity of the grab is utilized on each occasion.

This system is being replaced under the present development scheme by a permanent reeved 5-strand cactus grab with a 5 : 1 closing force, of 85 cu. ft. total capacity when heaped. This type of grab has been observed in operation on lump limestone of the type used at Abbey melting shop (approx. 6–8-in. dia. pieces) and is known to be capable of picking up a full load. This quantity approximates to the capacity of two boxes, which are 40 cu. ft. each. To facilitate filling two boxes simultaneously, there will be suspended from the bridge girders of the crane a hopper with two discharge openings separated by the distance between two boxes when resting on the bogie. The hopper will be located over the boxes, and the grab of limestone or other material will be discharged into the hopper, and thence into two boxes. The operation will be quick, and there should be very little spillage.

SLAG AND SKULL BAY

The 400-cu. ft. slag ladles are conveyed to the slag bay on double ladle carriages. The slag bay consists of an open gantry, with a railway track running along each side, between which there is a basin about 8 ft. deep. The dimensions of the basin are 400 ft. long × 44 ft. wide × 8 ft. deep, and spanning the gantry are two 50-ton cranes with 20-ton auxiliary hoists. Each slag ladle rests in a bale, and is picked up by the crane using a beam and arms slung from the main hook. The hook on the auxiliary hoist engages with lugs on the bottom of the slag ladle, and slag is tipped.

The slag is immediately watered by means of large jets, of which there are three situated along the length of the slag bay. Following this, a magnet is attached to the crane and used to lift up and drop a 10-ton ingot from the maximum height of the crane lift on to the slag, in order to break it up. The magnet is also used to search the broken slag for scrap, which is transferred to the skull bay for cleaning from slag and breaking down to box size.

The skull bay is an extension of the slag bay. The gantry of the slag bay carrying the two 50-ton cranes is extended through into the skull bay, and in addition there is a high-level gantry carrying a 15-ton crane.

After the slag has been broken and searched, a grab is placed on the crane and used to load the crushed slag, usually into 12-ton tipping lorries for conveyance to the tips. Some slag is used, however, by the blast-furnaces, and for this purpose has to be graded in size to less than 6 in. The slag for this purpose is loaded into 20-ton railway wagons which go to the blast-furnace tipplers. To effect the grading, a grille with holes of the correct size, set at 45° to the horizontal, is rested on the wagon, and the slag is discharged from the grab on to the grille. The undersize falls into the wagons, whilst the oversize shoots off back into the slag basin. The total slag handled each week is about 3600 tons.

In the skull bay there is a breaking pit about 12 ft. deep, lined with 3-in. thick slabs of steel, backed by heavy baulks of timber and strong piling. The high-level crane gantry in this bay is 68 ft. above rail level, which, together with the depth of the pit, gives a total drop of about 80 ft. The 15-ton crane on the high-level gantry fitted with a magnet is used for lifting and dropping the breaking weight, which consists of a 4½-ft. dia. spherical ball of cast steel, weighing about 7½ tons. The total of scrap, moulds, skull, etc., broken by the skull breaker is about 900 tons/week.

Steel skull from the 200-ton casting ladles cannot be broken at the skull breaker, because the steel is so low in carbon (less than 0·07%) that it simply will not break under the ball, but bends all ways. A surprisingly small quantity of steel skull of this type is made—probably not more than 50 tons per week out of an ingot make of 18,000–20,000 tons—but what there is has to be sent to the scrap preparation area for burning to box size.

SCRAP PREPARATION

This is somewhat rudimentary at present, but considerable developments are in prospect. The existing organization consists simply of the following. Two 10-ton Diesel-driven crawler cranes are used for handling excess scrap and pig iron into and out of stock by means of magnets. Two 10-ton Diesel-driven rail cranes are used for handling oversize scrap into and out of stock dumps and for spreading this type of scrap on the ground for burners to cut to box size. The oversize scrap treated in this way includes the output of defective and scrap sheets from the Abbey mills, both the cold-reduction and the hot-strip mills and their cut-up lines.

In addition the Diesel rail cranes service a small guillotine shear used for shearing defective sheets to box size. The output from this shear is banded into bundles weighing about 1 ton.

To improve this situation in the future, it is proposed to install a large hydraulically-operated bundling press which will have a press box 9 ft. wide × 10 ft. long × 3 ft. deep, and will make a bundle about 24 in. sq. × 72 in. long, weighing about 25 cwt. This will take the output of reject material from the mills, and will also press a certain amount of purchased light cuttings; it is expected to produce about 2000 tons of bundles per week.

This will transform the scrap-handling situation, since the actual quantity of light steel sheets from the mills (which at present, even after burning, will only give about 4–8 cwt. per 40-cu. ft. box) constitutes a great embarrassment to expeditious scrap handling at the scrap bay, as well as to rapid furnace charging.

The press will be serviced by two 6-ton tower cranes with 60-ft. radii of operation, one operating on each side of the press on parallel rail tracks. The cranes will handle the scrap into and out of scrap dumps, feed the press, and load the bundles into 60-ton railway wagons for transfer to the steel

plants. Cactus grabs will be used for handling the scrap into the press box.

Situated near the press and in such a position that it may also be serviced by the 6-ton tower cranes will be a new crocodile shear for cutting up oversize pipes, bars, girders, etc.

COMMUNICATIONS

Effective communications are essential on a plant as large as Abbey melting shop, and the following methods are in use :

(1) Radio telephones from ingot-traffic controller to locos on ingot traffic. This is a two-way arrangement, the loco being able to call the controller and *vice versa*
(2) Radio telephones from stage locos to stage-traffic controllers (also a two-way channel)
(3) Public address system operable from the sample passer's office, scrap-bay foreman's office, casting-bay foreman's office, and mould-bay foreman's office to all parts of the melting shop including furnace stage, mixer bay, charge-holding bay, scrap bay, raw-materials bay, valve arch, mechanical foreman's office, electrical foreman's office, casting bay, and mould bay*
(4) Automatic telephones in all operational offices for communication to other departments within the works
(5) Private-line telephones from each furnace to strategic points, such as mixers, scrap bay, boilers, laboratory, casting bay, etc.
(6) The sample passer's office only has an external national telephone.

By judicious use of these means of communication, little or no delay is experienced in contacting and instructing all classes of personnel, with a considerable resultant increase in operational efficiency.

OXYGEN

The use of oxygen has recently been developed for the purpose of assisting bath decarbonization, particularly the problem of speeding up the removal of carbon in the region below 0·10%, where the O.H. furnace is a very poor performer. The technique is still being developed, but it may be stated succinctly at this stage that the oxygen is driven into the bath in the form of a jet issuing from a water-cooled tube situated about 4 in. above the surface of the slag. The water-cooled jet tube at Abbey is introduced and withdrawn vertically through a hole in the furnace roof. The point of impingement is as near to the centre of the bath as possible. The jet head is of special design and is made of copper for a length of 12 in. back from the orifice.

The hole in the roof has a concealed water-cooled annulus through which the oxygen tube passes. This system has been entirely successful and avoids the great inconvenience of entry and withdrawal through the back wall, which is much more complicated mechanically and fouls the back stage considerably. In particular there is no trouble with the hole in the roof during the normal life of the Abbey furnace roofs (12–13 weeks).

The oxygen is used at a pressure of 150 lb./sq. in. at the jet and delivers at a rate of about 35,000 cu. ft./hr. The life of the jet head would be fairly high before complete failure, but a change is made after about 20 blows, since chamfering is then occurring round the periphery of the orifice, which reduces the penetrating power of the jet. The chamfer is renewed by copper welding.

As stated, the system is still in course of development, but the present practice is to start the oxygen blow when the carbon content is 0·35% or below, provided that the bath is clear-melted, or very nearly so. The delivery of a volume of oxygen proportional to the carbon content of the bath at the start of the blow will reduce it to that required to meet the 0·07% specification. A sample is sent to the laboratory at the same time as the oxygen blow begins. When the carbon analysis is available, the quantity of oxygen required is calculated, and when this amount has been delivered, the furnace is prepared for tapping. Further samples are not actually necessary so far as carbon is concerned.

During the oxygen blow, the oil input can be reduced on the average to approximately half that required without the use of oxygen. This constitutes a considerable saving in actual oil consumption, which goes some way to paying for the oxygen used.

The oil/air ratio is, however, appreciably increased during the oxygen blow, since a considerable volume of combustible gas is generated at the reaction zone around the jet, and additional air is therefore provided to burn this gas as a fuel. The central location of the jet, which is made possible by the method of introduction through the roof, facilitates the full use of this gas as a fuel, whatever the direction of flow through the furnace. From either direction there is a full half-bath-length in which to develop and burn the flame. In the Abbey furnaces this provides about 26 ft. for the combustion of the gas.

The actual saving in tap-to-tap time is about 1¼ hr. if the oxygen is applied at about 0·30% C with the bath clear-melted. This being the case, the use of oxygen, when this is possible on a continuous basis, should give a welcome reduction in fettling and bad bottoms.

The reduction in the fuel input may also assist this. The oxygen jet generates heat actually in the metal bath itself, and the consequent lower fuel input appears to give lower slag temperatures, and also lower temperatures of the roof and linings of the furnace. There is a possibility, therefore, that roof life may be extended, and the fettling may be reduced.

The distance from the bath to the crown of the roof in the Abbey furnaces is 8 ft. 0½ in., and no throw-up of slag to the roof has been experienced during blowing, which might cause erosion of the brickwork. Production of brown fume is not found to be excessive if the oxygen blow begins below 0·35% C.

Acknowledgments

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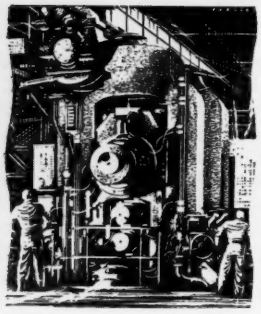
* This system is of the greatest possible value and is in continuous use for a host of purposes, such as calling all types of personnel for various duties, calling up tapping ladles, advising shop personnel of shunting procedures, dealing rapidly with emergencies, etc.



IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP

Guides and Strippers for Modern Rod and Bar Mills

By F. Starkey

SYNOPSIS

Various designs of bar-mill guide equipment are described, and the factors controlling the selection of the type of equipment are discussed. Particular reference is made to roller guides, and some of the guide-shop and mill-floor techniques of guide setting are included. 1045

THIS paper is concerned with the design and operation of the guide furniture of the modern continuous and semi-continuous mills. The range of equipment to be considered is mainly that used in the production of medium-sized bar and small-gauge rod, and, although it may be generally assumed that the product is steel, reference will also be made to the guiding of non-ferrous materials.

The wide diversity of guide designs which have been developed in various plants over a period of years makes it impossible to catalogue all of them in the restricted space of a single paper. Instead, an attempt will be made to classify the equipment in relation to the duty imposed upon it, and examples will be given of successful designs of each class.

The mill guide equipment can be subdivided into three main groups:

(i) Entry guides
(ii) Stripper or delivery guides
(iii) Twisting devices.

This classification will be followed and special reference will be made to the guide equipment used in the high-speed finishing stands of modern continuous mills.

ENTRY GUIDES

The function of a mill entry guide is to ensure correct delivery of the bar into the bite of the rolls. Sections to be presented to the pass in an unstable condition (*e.g.*, a diamond lying on edge) must be retained in this position whilst delivery is made. Some passes, by virtue of their form, are capable of automatically centralizing the bar before the bite occurs; otherwise, the accuracy of presentation to the pass must be controlled by the guide, which must also counteract any tendency for movement within the pass and hold the section in the correct position.

In this way, the design requirements of a guide handling a certain section are determined not so much by the shape of that section, but rather by the nature of the reduction to be undertaken. Therefore, it will be advantageous to examine a few reductions commonly met in the bar mill, and consider these aspects in greater detail before dealing with actual guide design.

Figure 1 shows a reduction being undertaken; the various scrap views are sections at XX, the point of roll bite. The diamond–square, square–diamond, and oval–stub-oval reductions at A, B, and C, respectively, have obviously no tendency to rotate in the pass and may be defined as stable reductions. They are also self-guiding, the inclined faces of the pass centralizing the bar before the bite occurs.

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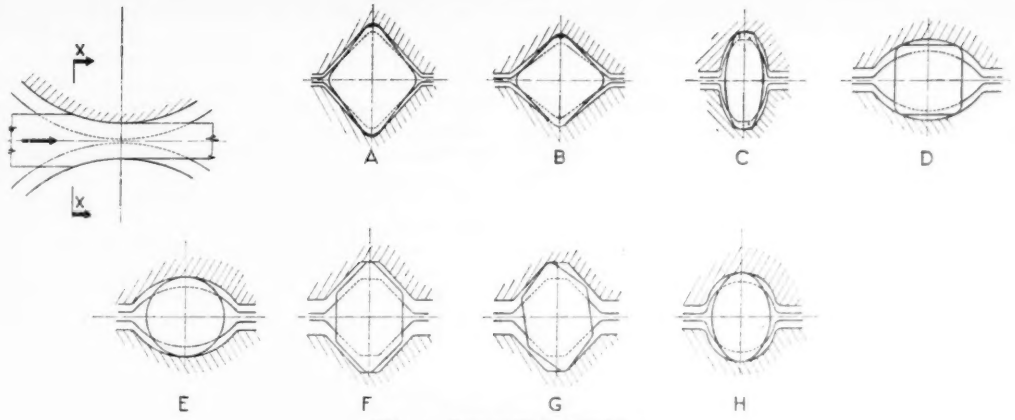

Fig. 1—Bar mill reductions

The square–oval and the round–oval reductions at *D* and *E* are similarly stable, but the degree of self-centralization depends upon the radius of the pass form. The amount of roll draft will also influence the self-guiding tendencies of a reduction, and a low-draft reduction has a greater tendency to grip the section in an eccentric position. The round–oval reduction is particularly difficult in this respect, especially with shallow oval pass forms. As the bar passes through the rolls the unbalanced rolling pressures set up will force the bar to the central position, but, owing to the heavy shearing thereby set up within the material, misformed and possibly split nose ends will result, increasing the likelihood of cobbles.

The reduction at *F* is unstable. Since the dimension over the corners of the pass is greater than that over the roof of the pass, the unstable hexagon section will heel over into the position shown at *G* to produce an unsymmetrical section.

In the oval–round example at *H*, the oval section

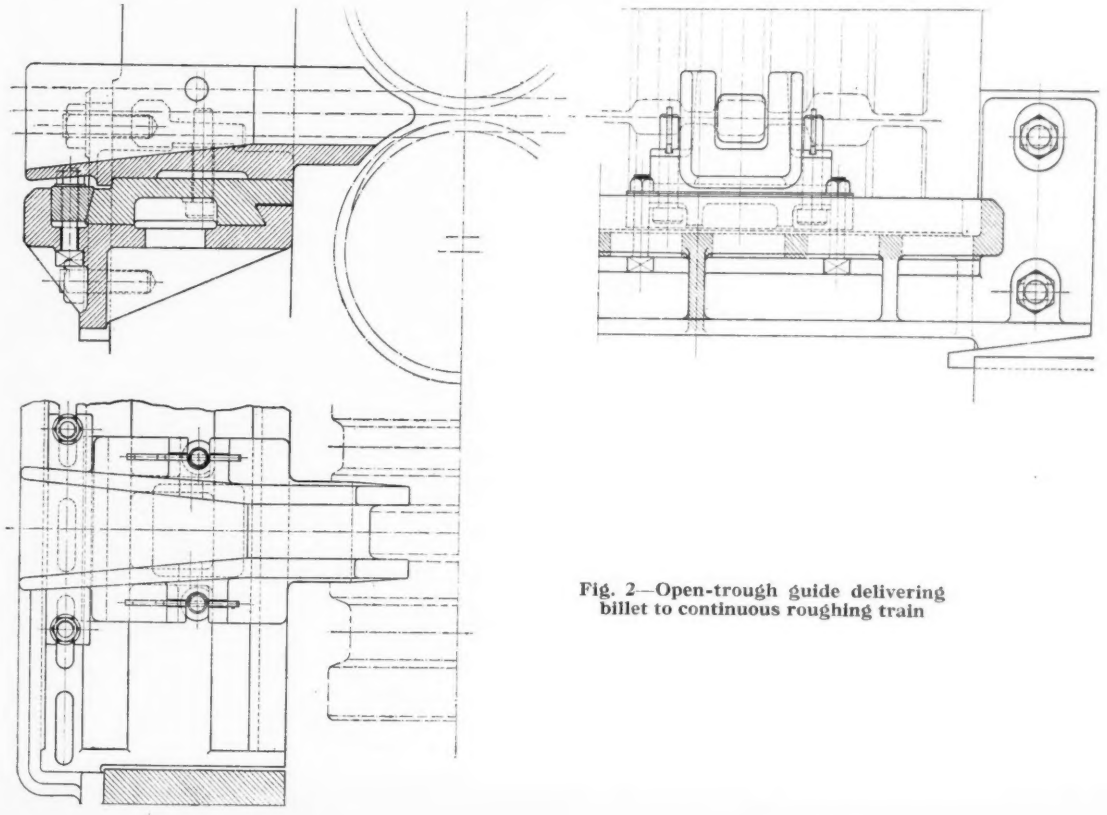

Fig. 2—Open-trough guide delivering billet to continuous roughing train

is unstable and, the round pass profile being unable to exert any resistance to rotation, the bar will 'turn down,' twisting through 90° to be rolled flat by the roll barrel.

A further point which should be considered is the possible effect upon the stability of the section of slight under- or overfilling of the pass. For instance, *F* is an example of an overfilled horizontally rolled hexagonal section. An underfilled section would have flat top and bottom surfaces which would be more stable, until, when the width of the flat surface was equal to that of the roof of the pass, the reduction would be both self-guiding and stable.

Considering this information in relation to guide design, examples *A*, *B*, and *C*, being both stable and self-guiding reductions, require that the entry guide merely directs the bar towards the roll pass, which will automatically centralize the bar and retain it in the true position. The reductions at *D* and *E* require accurate presentation to the pass but, since they are stable reductions, the bar will thereafter be controlled by the pass. In examples *F* and *H*, however, the guide must maintain contact with the entire length of the bar through the rolls.

The simplest form of entry guide has thus merely to position the bar before a self-guiding stable pass, which will then automatically centralize it. Figure 2 is an example of this type; it shows an open-trough

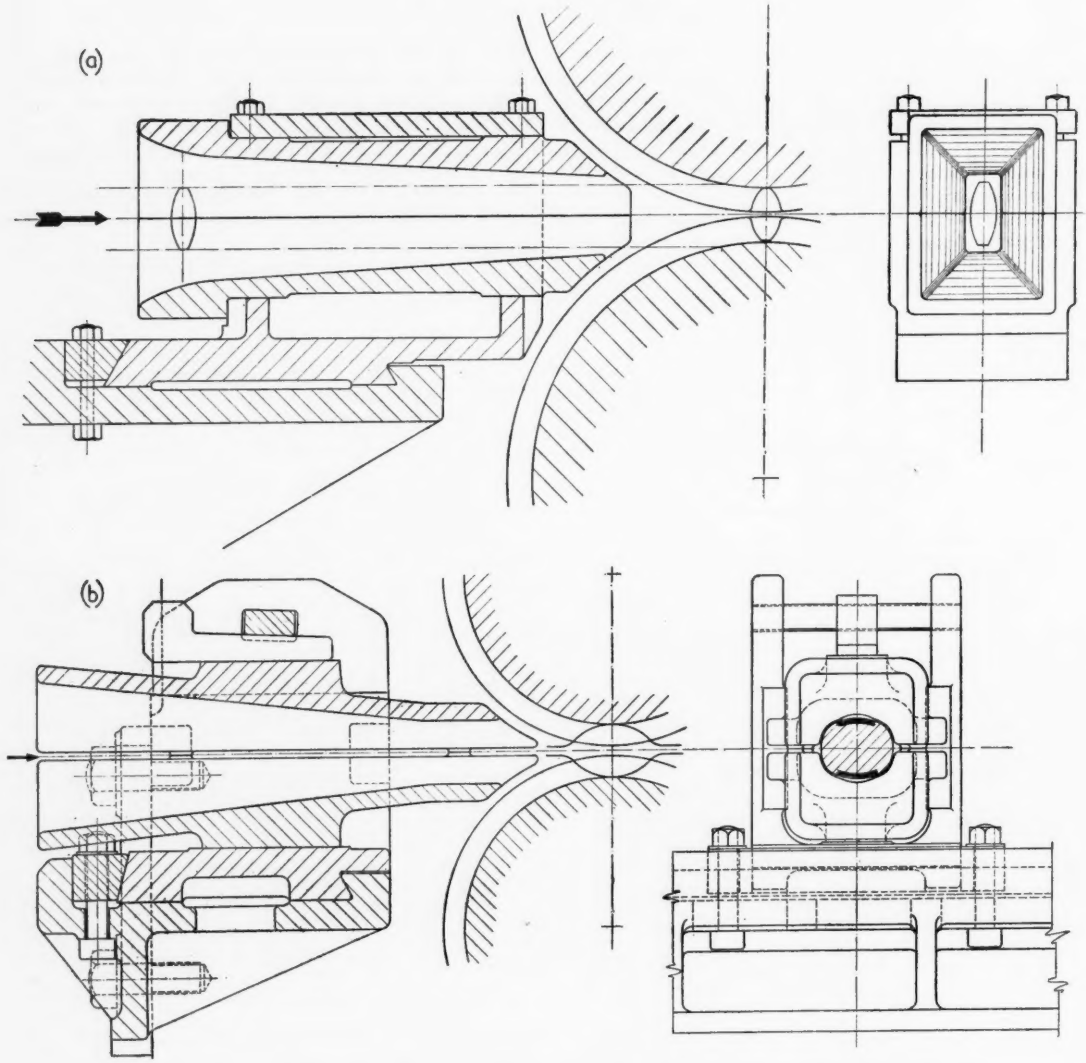

Fig. 3—(*a*) Intermediate-mill static entry guide; (*b*) roughing-mill entry guide

guide delivering the billet to the first roughing stand of a continuous mill. An ample bell-mouth is provided to receive the bar from the mill approach table and direct it at the pass.

The rectangular pass has relieved side faces, which will successfully centralize it before the bite occurs. The guide therefore has only to position the billet within the extremes of these faces for successful delivery to be obtained, permitting considerable clearance in the guiding surfaces and reducing the danger of guide breakage due to the jamming of bent billets.

A further example of a simple entry guide is shown in Fig. 3*a*. Here the stub-oval pass readily centralizes the thin oval bar and the reduction is stable after the fashion of Fig. 1*c*. The bar is being delivered from a repeater and a closed-top guide has been used to ensure accurate vertical presentation to the pass. The material is aluminium and the guide has been designed for maximum permissible clearance around the section to avoid pick-up; this, together with the generous taper of the bore, will ensure that no contact occurs between guide and bar after the material has entered the pass.

The guide shown in Fig. 3*b* is used in the roughing section of a continuous mill and is of more robust construction. The reduction is again stable but cannot ensure perfect centralization, and the side clearance in the guide has been reduced to a minimum.

To avoid the danger of overfilled bars becoming jammed within the guide, extra clearance has been allowed in the guide profile adjacent to the surfaces (shown shaded) produced by spread at the previous pass. The use of the cotter clamping device permits rapid release of the assembly to free cobbles trapped within the guide.

To compensate for the wear of the profile, small dressing pads are provided on the joint line which allow the guides to be rapidly corrected after use in the mill.

Guides delivering to unstable reductions are shown in Figs. 4*a–c*. That shown in Fig. 4*a* controls a roughing oval being reduced to a round. Owing to the tendency of the bar to rotate, the close-fitting guiding surfaces wear more quickly near the thin edges of the oval, and to allow easy and rapid correction of these surfaces and to increase the guide life, the joint line must be made along the major axis of the form. In this example of a vertical oval being delivered to horizontal rolls, the joint line must be vertical.

To enable trapped cobbles to be quickly released, side packers are used which can be easily removed, allowing the half guides sufficient float within the box to free the cobbled bar.

The rapid wear of the guiding surfaces permits the oval section to lean over to an increasing extent, and the resulting round becomes similarly untrue, affecting the form of the sections at subsequent passes.

In this particular application, used in the roughing stands of a continuous mill where throughput speeds are low, the rate of wear expressed in rolling time may not prove embarrassing. For guides handling unstable sections at higher speeds the wear of the controlling profile may necessitate frequent stoppages for guide adjustment, and it may prove necessary to use a roller guide.

The equivalent roller guide, shown in Fig. 4*b*, uses formed rollers positioned close to the mill rolls. By eliminating sliding friction from the surfaces supporting the section, the rate of wear is considerably reduced and the roller guide is capable of maintaining greater accuracy of control over the section for long periods of continuous use. The only function of the bell mouth is to deliver the bar into the grip of the rollers and to prevent the breakage of rollers from oversized or misformed bars.

In the second roller guide (Fig. 4*c*) the rollers are again used to avoid static friction, but here the material guided is aluminium and the rollers are used to eliminate pick-up and surface scratches, to which this material is particularly susceptible. The reduction is unstable in the manner of *F* in Fig. 1, and two short plain rollers are used, positioned near the mill rolls maintaining close contact with the vertical sides of the hexagonal section and holding the bar truly upright. On this occasion a fairly long guide was necessary to connect up to the handling equipment adjacent to the mill, and, to prevent the bar from making contact with these static surfaces, two further rollers are mounted near the entry end of the guide.

The duty of guiding aluminium is very light in comparison with that of steel-handling equipment, and it has been found that close-grained cast-iron rollers directly mounted on steel pins have a life of many weeks' continuous service. The simple open design provides good visibility and accessibility, and simplifies the introduction of water to cool and lubricate the exterior surfaces of the rollers and for flushing the central channel of the guide.

British practice favours the use of static guides wherever possible, owing to their initial low cost, and they will give satisfactory service provided that they are not required to restrain the bar against movement in the pass. When the latter characteristic is required, their life will be considerably reduced by the constant friction between the guiding surface and the hot bar. Provided, however, that surface finish is not of supreme importance and that the material is not unduly susceptible to scratching and pick-up, they may be used successfully, especially for short runs at low production rates.

Various hard weld deposits have been applied to the guiding surfaces of static equipment, which by virtue of their abrasion resistance give increased guide life by reducing the rate of wear on the critical profiles. There is some divergence of opinion about their suitability: some users claim satisfactory results with reduced guide costs, whereas others maintain that the extreme hardness of the material promotes excessive scratching and is responsible for a general deterioration of the surface finish of the final product.

When rolling material prone to surface defects, the incorporation of rollers into the nose of guides delivering to unstable reductions becomes a virtual necessity. Where long production runs of a steel product are to be undertaken, their use is desirable to retain accuracy of product form, which may prove difficult when using static equipment.

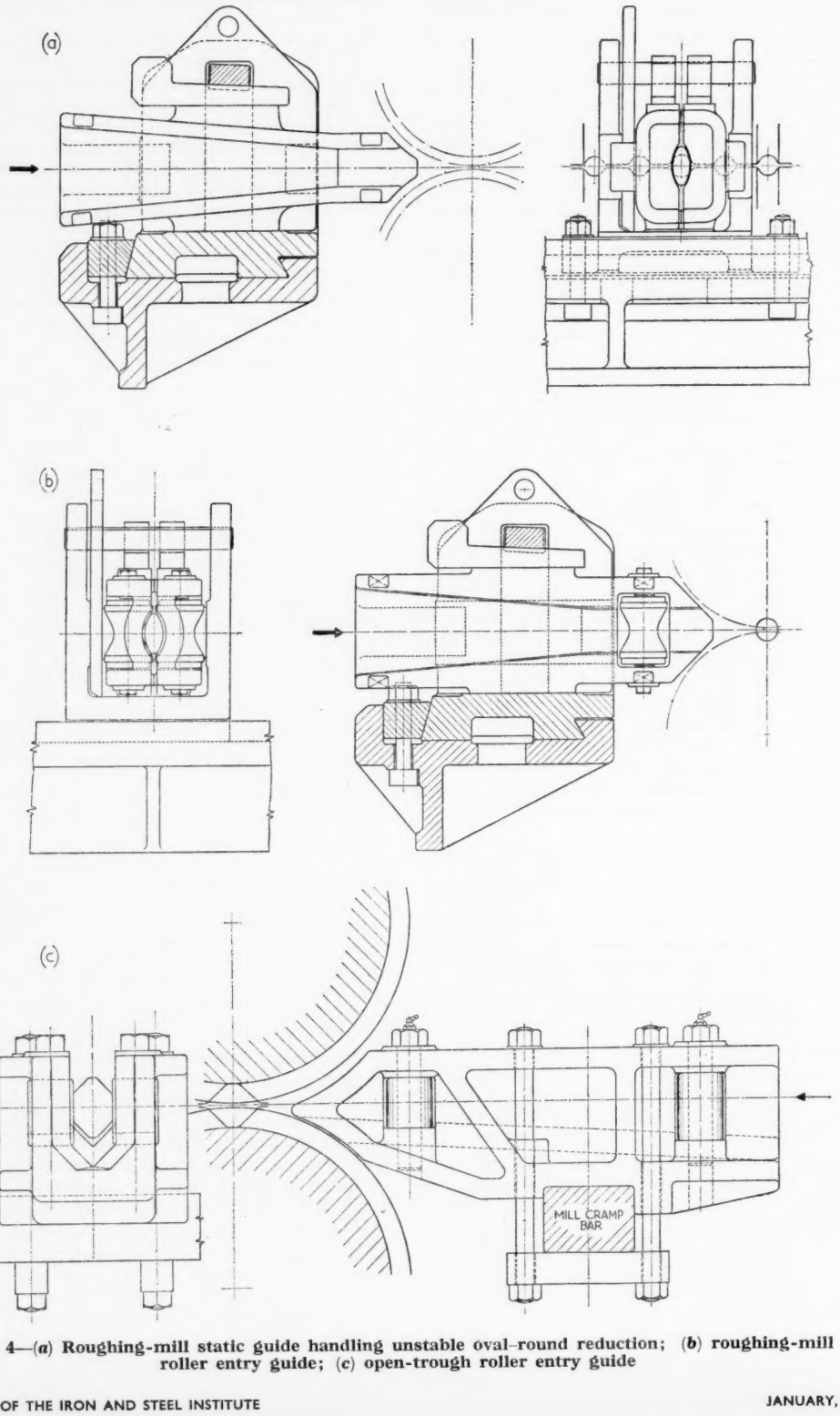

Fig. 4—(*a*) Roughing-mill static guide handling unstable oval–round reduction; (*b*) roughing-mill roller entry guide; (*c*) open-trough roller entry guide

By eliminating sliding friction from the critical guiding surfaces, the roller-assisted guide will have a greatly increased life, and, although the initial cost of the rollers may be high, it is normally found that the guide costs per ton of roller product are reduced. These circumstances can be further improved by strengthening such non-wearing parts as guide members and boxes, to avoid breakages due to cobbles and general misuse.

Furthermore, by avoiding the necessity for frequent production halts for guide changes and adjustments and by reducing the frequency of cobbles caused by worn guide equipment, the use of roller-assisted guides will result in a considerable increase in overall mill efficiency and an improvement in the form, accuracy, and surface finish of the product.

STRIPPER OR DELIVERY GUIDES

The simplest form of stripper guide exists in the hand-fed merchant mill, where the bar, by the use of unequal roll diameters, is directed against a single stripper blade suitably supported from the roll housing. The stripper normally fits against the bottom roll pass and acts as a wedge to part the bar from the grip of the pass and prevent it from collaring around the roll or cobbling within the roll housing. To strengthen the weak feather edge at the very tip of the stripper nose and to prevent frequent breakages, the stripper is set low and the bar is often delivered with a turned-down nose. In the hand mill this offers no serious trouble since, when the bar is looped on the mill floor and the nose is offered to the following rolls, the occasional bent nose can be levered through the guide by the tongsman.

In the modern bar mill using repeaters or manipulator trough gear, however, the stripper alone must control the delivery of the bar to this equipment. In straightaway continuous rolling, a bar that is not straight may not only either escape from or foul the inter-stand delivery troughs, but also has little resistance to end thrust, rendering it less capable of overcoming the resistance at the following roll stand. In repeated and straightaway rolling it is particularly important to ensure perfectly straight nose ends which will pass freely through the following entry guides, and for the same reason the strippers should ensure twist-free delivery between stands. Similarly, where bars must be twisted between passes (*e.g.*, to allow the section to pass round a repeater or, in the case of an oval–round or similar progression, through successive horizontal mills) the strippers must permit this rotation whilst still controlling the direction of the delivery of the bar.

Figure 5*a* shows the stripper guide assembly for a mechanized roughing stand. The stripper form is almost identical with that of the pass, except for a slight increase in the width of the flat top and bottom faces, to ensure that stripping takes place against these surfaces and avoids the wedging action produced by heavy contact against the inclined sides. A suitable bell mouth is provided at the entry end to strip the bar from the pass and direct it along the close-fitting guiding surfaces, whilst the nose of the stripper is dressed to bed accurately upon the pass surface.

The strippers are carried on hardwood blocks, the top blade being held in position by spring tension from a top anchor bar. These blocks have been found to be strong enough to withstand normal stripper loads. Their resilience effectively dampens the shock of the entry of the bar into the guide and protects the weak stripper nose; in the event of a cobble they form a safe breaking point, allowing the blades to be released before being seriously damaged.

To increase pass life by preventing constant rubbing of the stripper nose upon the pass surface, they are adjusted so as to have a slight clearance at this point. Entry of the bar into the stripper will cause it to rock upon the near support block and bed upon the pass surface at the moment of impact, further progress of the bar along the delivery faces forcing the stripper back to its original position.

The stripping of heavier bars such as are met in the roughing section of a continuous mill requires a much more robust assembly, and a typical example used in the delivery of a round bar is shown in Fig. 5*b*. The arrangement is very similar to that used for the entry guide unit previously described, and permits a high degree of standardization of small auxiliary parts. The carrier blocks in this case are of steel.

The ample bell mouth at the nose of the stripper is strengthened to withstand the arduous duty of repeated heavy blows and the feather edge is suitably relieved. The stripper should be bedded to the roll pass and adjusted to maintain a minimum clearance between these surfaces. This will ensure that the blades, whilst remaining rigidly clamped, can receive momentary support from the pass surface after slight deflections produced by stripping the bar from the roll and straightening the bent bar nose thus formed.

The profile of the stripper bore conforms closely to that of the pass, with increased clearance provided around the spread area of the section. The strippers are usually made of close-grained cast iron, which is economical and satisfactory in regard to service life, although it is found necessary to use steel strippers for guiding copper. The degree of finish required on the guiding surfaces depends upon the surface-finish characteristics of the rolled product, including the tendency for pick-up and the degree of accuracy required in the guiding faces.

This example is supplied with cast guiding faces. Particular attention is paid in the preparation of the mould to the surface finish of these faces, any surface irregularities appearing on the final casting being removed by hand dressing.

The previous example (Fig. 5*a*), where considerable accuracy of form is required, necessitates the dressing of these surfaces to suitable templates. Where a consistent demand exists for a particular stripper of this type, it is more economical to undertake batch production of spares, and to machine the profiles with suitable form cutters.

As in the case of entry guides, problems of maintaining control over difficult sections and avoiding the occurrence of surface defects produced by static guiding equipment have been solved by the introduction of roller equipment. The design shown in Fig. 5*c* successfully delivers 200-ft. lengths of the section

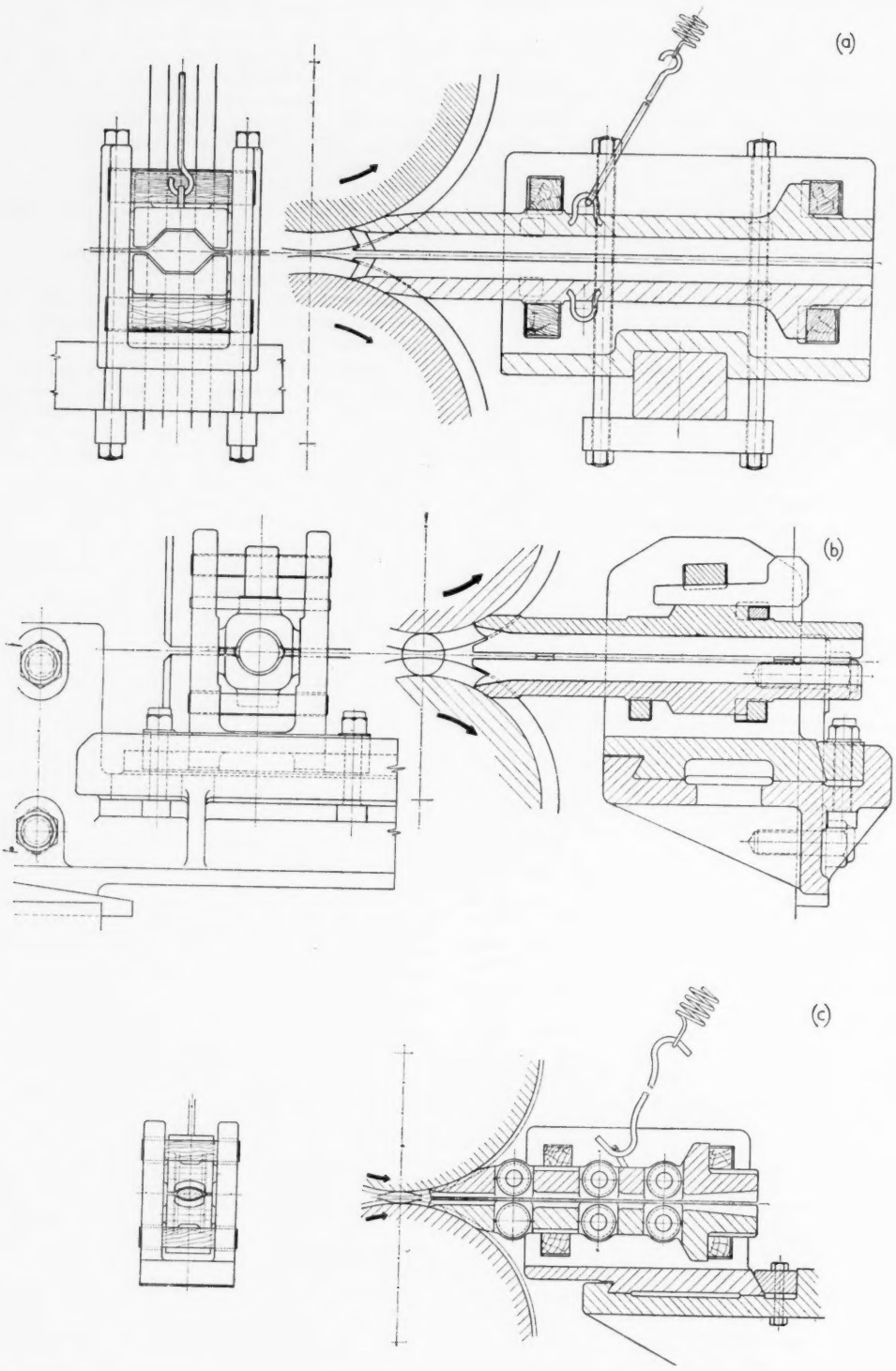

Fig. 5—(*a*) Stripper guide; (*b*) roughing-mill stripper guide; (*c*) intermediate-mill roller-stripper guide

illustrated, completely free from twist. The material is aluminium, and it is impossible with normal static strippers to apply sufficient control to the section without incurring serious scratching and pick-up.

The rollers are provided with self-lubricating heat-resisting bearings, and three pairs are used widely pitched to apply maximum control, the stripper groove being relieved to avoid contact with the bar. Form rollers are used to prevent marking of the bar, and, in spite of the rolling slip thus induced, very little wear is experienced. The strippers are fitted in the guide shop to grip a test section, and are finally clamped in the box by hardwood breaker blocks.

Suitably designed roller strippers could also be applied to the guiding of the steel bars, where the rapid loss of control due to the wear of static equipment must be eliminated. Thus the delivery of long lengths of bars to a cooling bed could be obtained without troubles arising from twisted sections. The installation of such a guide would undoubtedly be expensive, but the improved output resulting from its introduction, particularly by avoiding delays at the cold shear, would more than compensate for the initial outlay.

TWISTING DEVICES

The commonest form of twisting unit used in the bar mill is the static twister stripper, although roller twisters have recently been introduced to an increasing extent.

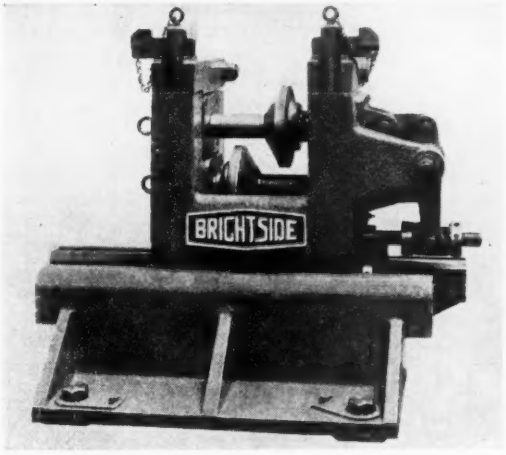

Fig. 7—Heavy roller-twister unit

The static unit shown in Fig. 6*a* employs a similar arrangement to the straight delivery unit previously used. Two identical half strippers are used, with a groove profile which consists of two opposed twisting faces each embracing somewhat less than a quarter of the surface of the section; the remainder of the groove form is relieved to give considerable clearance around the section.

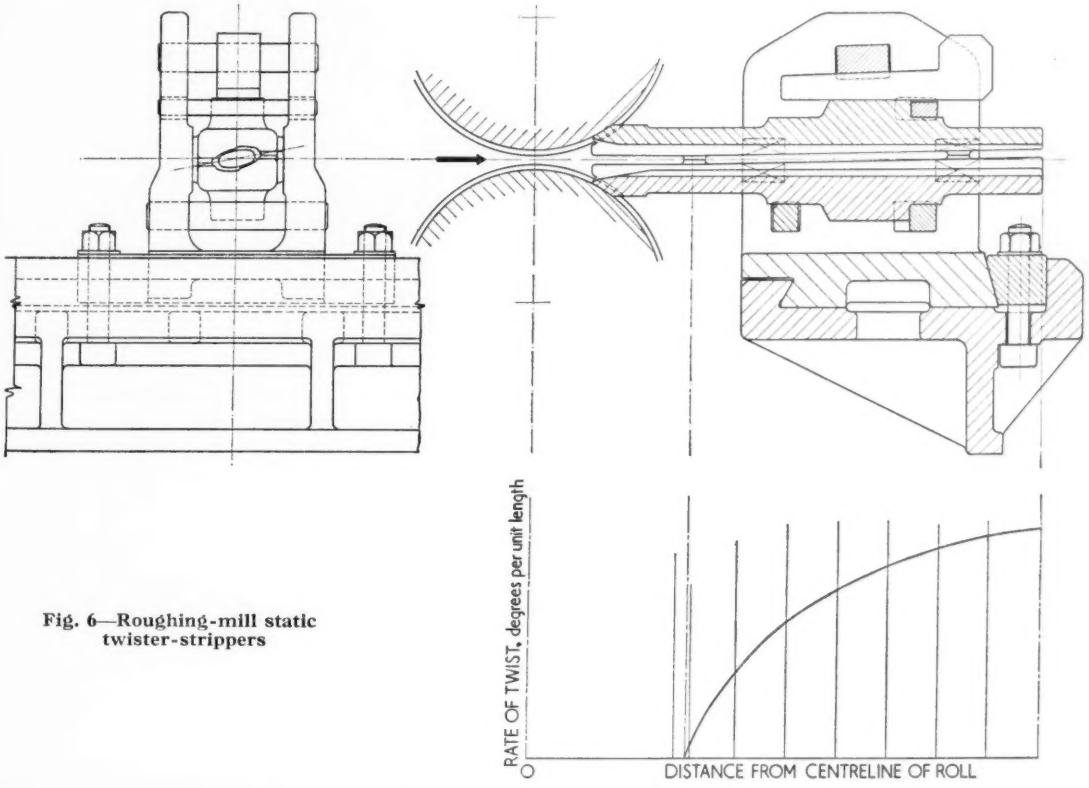

Fig. 6—Roughing-mill static twister-strippers

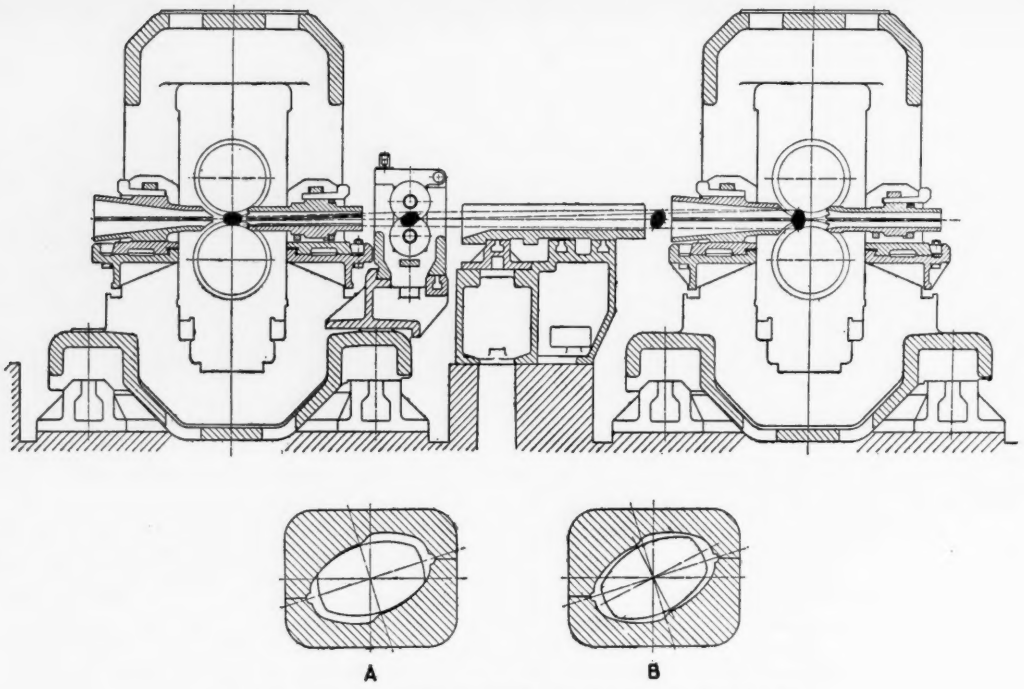

Fig. 8—Twisting guide set-up for continuous roughing mill

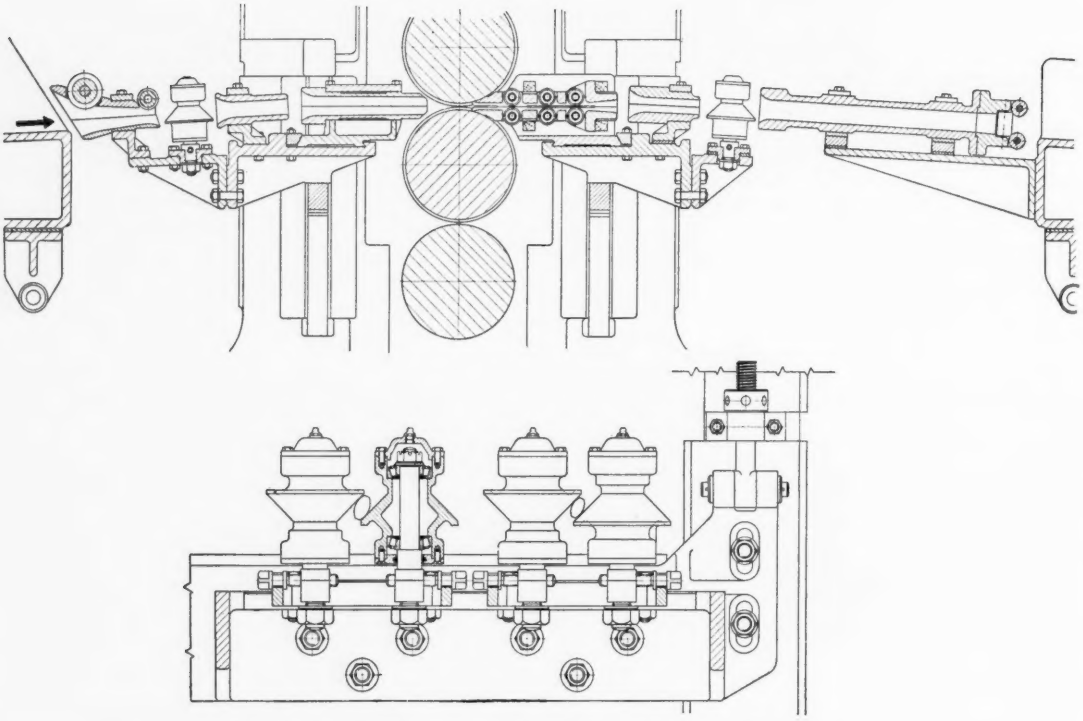

Fig. 9—Roller-twisters for non-ferrous intermediate mills

The nose of the stripper parts the bar from the pass and delivers the bar *via* a generous bell mouth to the twisting faces, which spiral at an even rate for the remainder of the stripper length. Because the twisting action does not begin until the end of the bell mouth is reached, the bar, which is twisting from the roll pass, is subjected to a gradually increasing rate of twist, shown graphically at *A* in Fig. 6, and results in a steady build-up of the twisting load.

However, the intensity of pressure, especially in the case of heavy sections, is still very high, and the high rate of twist necessary in the closely pitched stands of the continuous mill produces serious surface defects on the material and a high rate of wear of the twisting surfaces of the guide. This in turn results in a loss of the degree of twist induced in the bar and transfers some of the twisting duty to the following entry guide, increasing the resistance to the travel of the bar at this point, and thereby adding to the danger of cobbles.

To avoid these undesirable features the roller twister unit has been evolved. That shown in Fig. 7 is designed to handle a range of sections whose extremes are ovals of $5\frac{1}{2}$ in. $\times$ $2\frac{5}{8}$ in. and $1\frac{3}{4}$ in. $\times$ $\frac{5}{8}$ in., respectively. The working elements are two conical rollers which deflect the shoulders of the section and apply the required degree of twist. They are carried on spindles mounted on tapered roller-bearings, whilst heavy-duty roller-bearings absorb the axial thrust reaction.

To cater for the various sections handled and to permit adjustment in the degree of twist induced in the bar, the spacing of the rollers can be adjusted by a link mechanism. Each roller spindle has an equal and opposite movement retaining a constant pass line through the unit. By reversing the chocks, which have eccentric bores, the centre distance of the spindles can be increased and the larger sections accommodated.

The chocks are locked in position by swinging clamp beams and cotters, which give quick release for adjustment and allow the top spindle assembly to be swung clear to free a trapped cobble. Alignment with the pass is accomplished through a lead screw, ambushed in the unit base for protection against scale and water.

The rollers shown are designed to twist the oval sections up to the position of major axis vertical. The substitution of rollers with modified cone angles will allow the unit to be used upon other sections and will convert it for a down-twisting application.

Figure 8 shows this unit incorporated in the guide equipment of the roughing train of a continuous mill, and positioned immediately after the stripper guides. The use of the normal straight-delivery strippers in an application of this type has several disadvantages which are particularly undesirable when handling heavy sections. Firstly, if close-fitting stripper profiles are used to give accurate direction control within the inter-stand table troughs, they are required to supply a counter-torque equal to that applied by the roller unit. The resultant heavy shearing produces serious surface defects, comparable with those obtained with normal static twister strippers, and the high rate of wear induced in these holding surfaces would result in a rapid loss in the degree of induced twist. On the other hand, if the strippers were relieved towards the delivery end to allow the bar to twist from the rolls, heavy shock loading would be imparted to the twister rollers.

A more satisfactory arrangement is achieved by re-introducing twister strippers, which are designed to apply a degree of twist somewhat less than that required. The bar passes through the guide, making contact with the twisting faces as shown at *A*, the torsional resistance of the bar ensuring straight delivery of the axis of the section.

The roller twister unit is adjusted to apply the final degree of twist to the bar such that the latter will have completed the desired rotation at the bite of the following rolls. Immediately upon entry into this unit

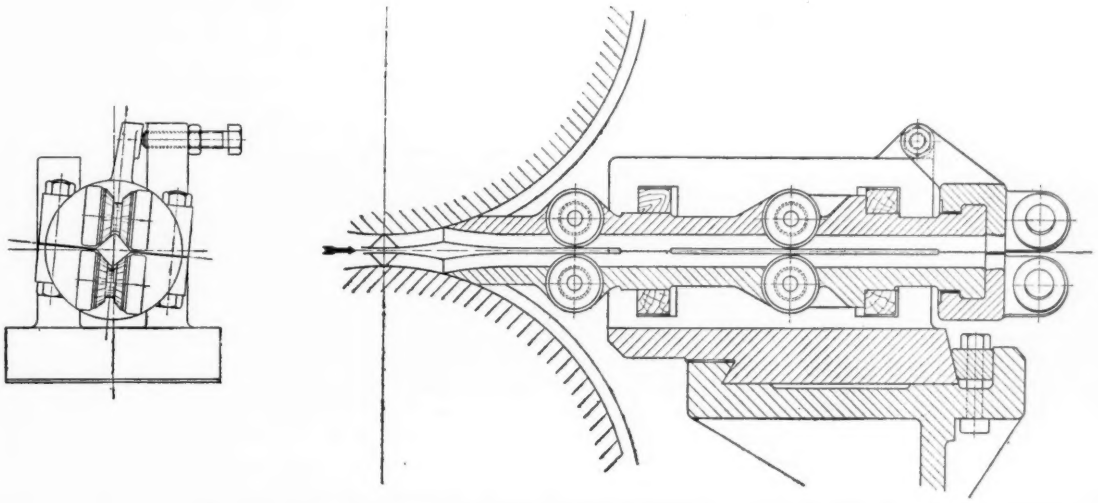

Fig. 10—Roller-stripper–roller-twister unit for small non-ferrous sections

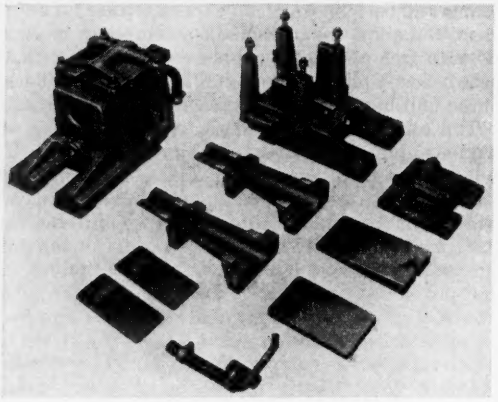

Fig. 11—Finishing-mill static entry guide

the bar is given an additional twist, and that passing through the twister stripper moves away from the twisting faces and, as shown at *B*, passes freely through the body of the guide.

In this way, marking of the bar due to heavy static twisting is confined to the nose of the bar, most if not all of which will be removed in subsequent nose-cropping operations. Furthermore, the initial twist applied by the strippers results in improved entry of the bar nose into the roller unit, reducing the impact of the bar upon the rollers and increasing their service life by avoiding the tendency for marking and pitting of the working faces.

The reduced period of contact between bar and stripper reduces the wear on these surfaces to negligible proportions, and, since the final degree of twist is applied by the roller twister, the strippers will still function satisfactorily after considerable wear, the only criterion determining replacement being the ease of bar entry into the twister rollers. Also, owing to the wide pitching of the roller twister unit and the holding point at the pass surface, the low rate of wear of the conical faces of the rollers has a negligible effect upon the degree of twist applied, and the co-ordinated use of these two units gives a stable and economical guide arrangement capable of trouble-free operation over extended periods, whilst the near-elimination of frictional resistance to the passage of the bar considerably reduces the power consumption of the mill.

An example of the twisting of smaller sections is shown in Fig. 9. The stub-oval section delivered from the left-hand repeater is directed towards the twist rollers by a normal catching guide and is twisted against the resistance of the repeater path, passing through a further clearance guide into the roll entry guide. The reduction is stable and the guide is merely required to give reasonably accurate presentation to the pass.

The material being rolled is again aluminium and the roller stripper unit of Fig. 5*c* is shown on the outgoing side of the rolls delivering to a second twister unit, twisting the slim oval section up to permit easy passage around the repeater path. In this case the resisting torque is supplied by the last pair of stripper rollers, and the twisting bar is deflected by a further roller-assisted guide before entering the down-gradient repeater.

The comparatively light twisting loads permit the use of overhung roller assemblies mounted on stationary cantilever shafts, the open-top design giving easy release to trapped cobbles. The rollers are designed for lightness to reduce inertia drag, and are easily adjustable in relation to each other and to the mill pass line.

The twisting of very small sections can be achieved by the use of the combined roller-stripper–roller-twister unit illustrated in Fig. 10. The twister head, which is mounted directly on to the end of the stripper blades, carries rollers identical to those used in the stripper unit. A jacking screw is provided to adjust the degree of twist applied, and clamping screws then lock the head firmly in position. This unit has proved successful in the guiding of the non-ferrous sections, build-up on the guides and pick-up on the material having been eliminated at this point.

Whilst cast iron has been found to be suitable for most static twister applications, the choice of material for the rollers themselves has provided scope for much experiment. Cast iron has proved satisfactory for rollers guiding aluminium, and good performances are obtained from the use of medium-carbon steel rollers in copper mills; for the arduous duty of handling steel, cast and forged alloy steels have been used with varying degrees of success, and on at least one occasion bronze rollers have been used. Very satisfactory results have been obtained from rollers whose working surfaces are built up of welded deposits of Stellite.

This material is costly and the rollers are therefore expensive, but the high tonnages achieved tend to show them to be more economical than other types, and it would seem that it is becoming established practice to use this type of roller.

HIGH-SPEED GUIDE EQUIPMENT

High-speed finishing mills are used to obtain fuller utilization of the previous roughing-mill stands, and as such frequently use product speeds approaching 3000 ft./min., whilst small-gauge rod mills may reach a speed of 5000 ft./min.

With these high speeds and the small bar sizes encountered in this part of the mill, accuracy of control becomes of prime importance. Small sections travelling at high speed will almost certainly cobble if they have to be deflected to any great extent to enter the entry guide unit. The slight loop or kink thereby produced weakens the bar and renders it less capable of overcoming the resistance at the entry guide and at the bite of the rolls.

To obtain tension-free rolling in the straightaway mill provision must be made for looping between stands, and so restrictive inter-stand guide gear cannot be used. Thus it is apparent that the high-speed stripper units must control the bar in its passage between mills and must deliver perfectly true straight bars accurately aimed at the following pass.

In plants having high-speed repeaters, true delivery must again be made so that the bar supported by the

repeater path will have sufficient resistance to buckling to enter the following rolls.

The advent of the high-speed mills emphasized the need for guide equipment other than the static friction type previously used. This was particularly desirable in the case of mills producing accurate rounds, where it was found impossible to retain the required accuracy of control of oval sections entering round passes, without frequent production halts to adjust and renew friction guides. Improved engineering materials, together with much experiment and development, have led in recent years to the evolution of the highly successful roller guide units in use today.

Static guides are, however, still successfully used for the high-speed guiding of bars into stable passes, where they are merely correction units ensuring accurate presentation to the pass. A typical example is shown in Fig. 11, guiding a round section entering a horizontal stand in a continuous mill.

The half guide members follow a similar design to those previously described and have a slow-taper bell mouth to ensure easy entry of the bar and to straighten hooked tail ends. The latter can prove troublesome and are encouraged when rolling with excessive loops at high speeds. Under these conditions the bar tail tends to whip and produce a badly hooked end, which blocks the mouth of the entry guide and cobbles the next bar through the mill. The remedy is to reduce the extent of the loop by adjusting the mill speeds and approach the condition of a straight bar which will pass smoothly between stands.

The guide box is provided with height adjustment by wedge gear, and is clamped to the mill breast beam by wedge slips. The guide elements are secured by a top clamp plate which has been adapted to serve as a water box. Water piped to this point is divided into two jets directed at the root of the pass groove immediately before the bite of each roll. On contact with the hot surfaces of the bar and pass the water is transformed into a buffer skin of high-pressure steam and has been shown to improve roll life considerably.

The danger of pick-up and general surface defects, which are always present when friction guides are used, still exists, but can be reduced by careful design. The correct balance must be achieved between the provision of sufficient working clearance to avoid general contact, and the retention of accurate roll presentation. This can be aided by reducing the length of the restrictive portion of the guide element, and the provision of a smooth ground finish to these surfaces will at least tend to delay the appearance of surface irregularities, and give smoother entry into the guide. At the same time, precision setting of strippers giving accurate delivery through the entry guide and the maintenance of near-straight bars by careful speed trimming will reduce all contact to a minimum.

Where surface finish is of prime importance and where trouble has been experienced by repeated cobbles due to excessive friction in the entry guide, or by distorted nose ends resulting from inaccuracies of bar presentation, the use of roller entry guides can be expected to produce a considerable improvement.

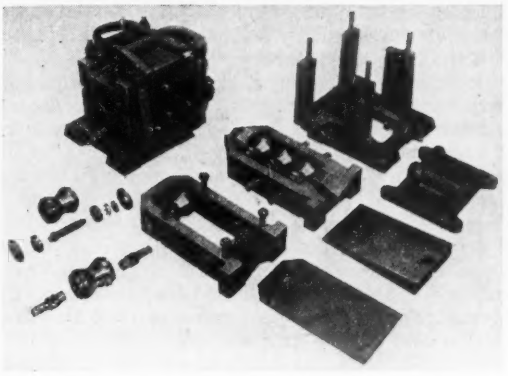

Fig. 12—High-speed roller entry guide

Where finished stock must be consistently accurate to gauge, the use of roller guides to retain control of bars in high-speed unstable passes becomes a necessity if really efficient working of the mill is to be achieved.

The roller guide shown in Fig. 12 has proved very successful in guiding ovals for the production of steel rounds. The rollers are provided with internally mounted tapered roller-bearings carried upon a stationary spindle and secured by locknut and tab washer. Clip-on end shields retain the lubricant and afford protection against the ingress of scale and water. The protruding spindle has tapered extremities, which seat in the socket ends of support screws carried in the half guide frame; they permit the roller assembly to be adjusted axially and provide an efficient method of locking it in position.

It is thought that this arrangement is unique in so far as it permits the roller to be completely assembled before being introduced into the guide frame; for this reason it has several advantages. Firstly, the correct assembly of the roller-bearings depends upon attaining the exact adjustment of the locknut. This is easily achieved by incorporating a small holding fixture which grips the taper spindle ends and allows full visibility and easy access to internal parts. Secondly, the roller, charged with grease and effectively sealed, can be held in stock until required and then introduced into the guide frames more quickly than with other designs, at the same time avoiding the risk of the intrusion of grit and scale, which adheres to the guide frames after service in the mill.

Vertical jacking screws give adjustment of the centre distance of the guide frames and allow several similar sections to be controlled by the same guide assembly, whilst adjustment of the height to the pass line is achieved by wedge gear and packers. The guide frames are clamped by a top plate; this is again used to transfer water to the roll groove, and also to the rollers themselves, to guard against overheating through constant contact with the hot bar and to act as a lubricant for the active faces of the rollers.

The bell mouth delivers the bar to the rollers and protects them against breakages incurred by the shock

of hooked ends. Sufficient clearance is allowed at the static entry and delivery bell mouths to avoid contact with the bar passing through the box.

During service in the mill, lubrication should be carried out at regular intervals if the bearings are not to have their normal life of several months reduced to a few hours. It is especially important in that the presence of a seized roller is almost undetectable, and almost invariably results in the roller being scrapped. Frequency of lubrication will depend upon the type of protection afforded to the roller-bearings; in the design shown it is so efficient that a rate of approximately once in every four shifts is ample, and has the advantage of avoiding spent grease building up within the box and picking up scale and slivers.

The guide shown is designed to guide a range of oval sections producing rounds from $\frac{15}{16}$ in. dia. to $1\frac{25}{32}$ in. dia.; a smaller model handles leading ovals for sizes down to $\frac{3}{8}$-in. dia. rounds. The reduced wear resulting from rolling contact allows straight-sided **V** grooves to be used in preference to formed shapes fitting closely against the section, and increases the range of sections guided by each roller.

Figure 13*a* shows the range of sections handled by a typical roller. The groove design must be such that contact is achieved near the shoulders of the section, again avoiding contact with the spread area of the bar. The line subtended from the points of contact to the centre of the section form an angle α which may be termed 'the angle of stability.' To control the section against rotation this must be greater than 90°. Furthermore, the larger this angle can be made the less the section can rotate for a given amount of wear, and hence a longer service life will be obtained before replacement or adjustment becomes necessary.

The thirteen sections shown are leading ovals which are all controlled by the same roller, whilst the large range of rounds whose extreme sizes are shown in Fig. 13(*B*) can also be accommodated. This well illustrates the adaptability of the roller guide, and in fact the use of this equipment reduces the quantity of guide members required to control a given range of sections, and favourably offsets the increased cost of these more complex units.

The design of the roller groove is determined by the shape of the section to be guided. Thus, the leading ovals shown in Fig. 13(*A*) require a 110° included-angle groove form, whilst the slimmer oval illustrated in Fig. 13(*C*) must have a groove angle of 130° to retain stability. The hexagon leader illustrated in Fig. 13(*D*) is guided satisfactorily by a flat-faced roller.

The controlling design features of the roller guide unit are the overall height dimensions from the pass line through the box, and the centre distance of the mill rolls and the nearest roller. Unnecessarily large rollers increase the size of the box and result in large

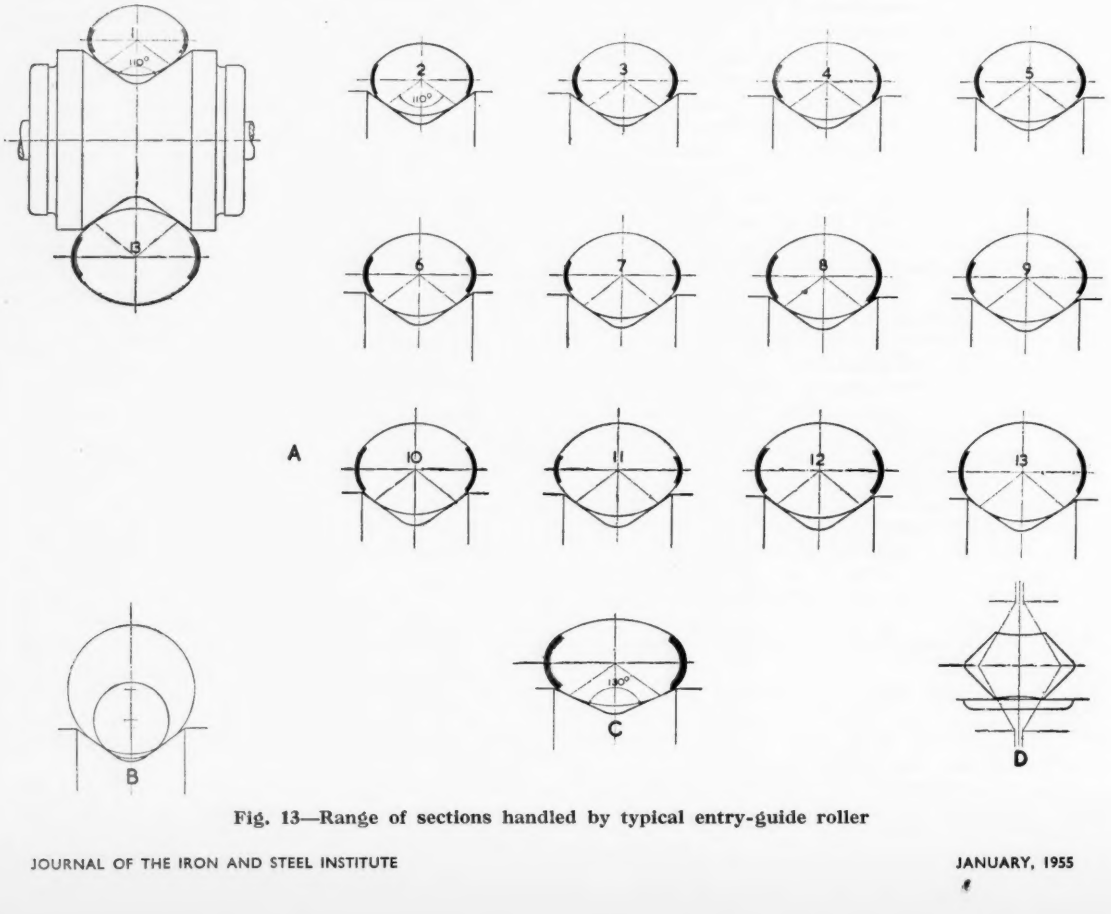

Fig. 13—Range of sections handled by typical entry-guide roller

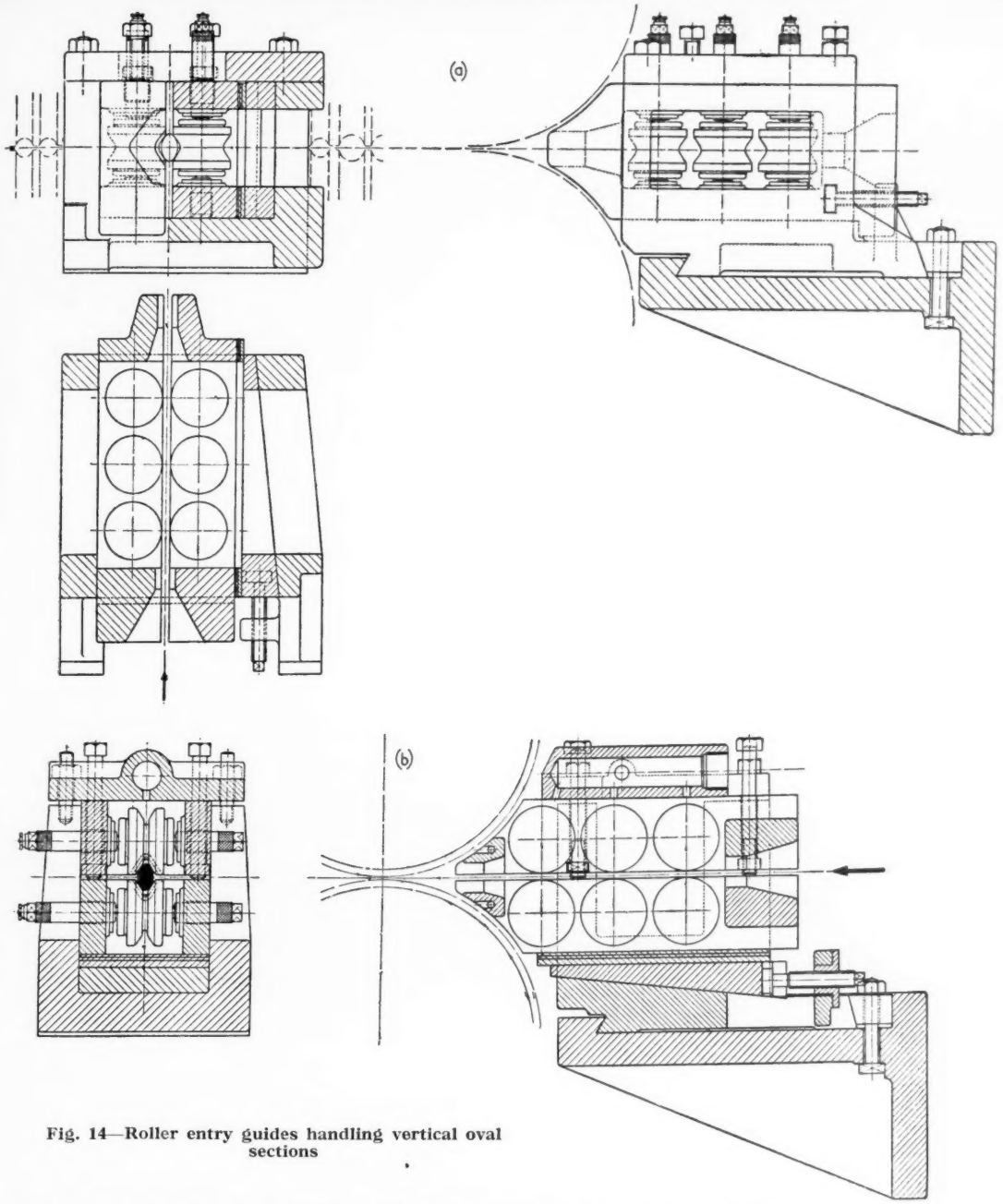

Fig. 14—Roller entry guides handling vertical oval sections

end collars on the rolls. For full utilization of the roll face, therefore, the rollers, and indeed the whole guide assembly, must be reduced to minimum proportions consistent with adequate strength.

The centre distance between the last roller and the rolls becomes critical when guiding small unstable sections which will turn down unless supported close to the roll bite. If sliding friction is to be eliminated no further support can be offered to the section after this point, and it is essential that the rollers be positioned as close to the rolls as possible. Furthermore, this is equally important when using roller guides before any unstable reduction, to avoid frequent cobbles caused by misformed tail ends produced by the last few inches of the bar turning down after leaving the grip of the last roller.

The guide assembly (Fig. 12) is shown delivering ovals with their major axis horizontal into a vertical mill. When vertical ovals are to be guided, a slightly different arrangement is required.

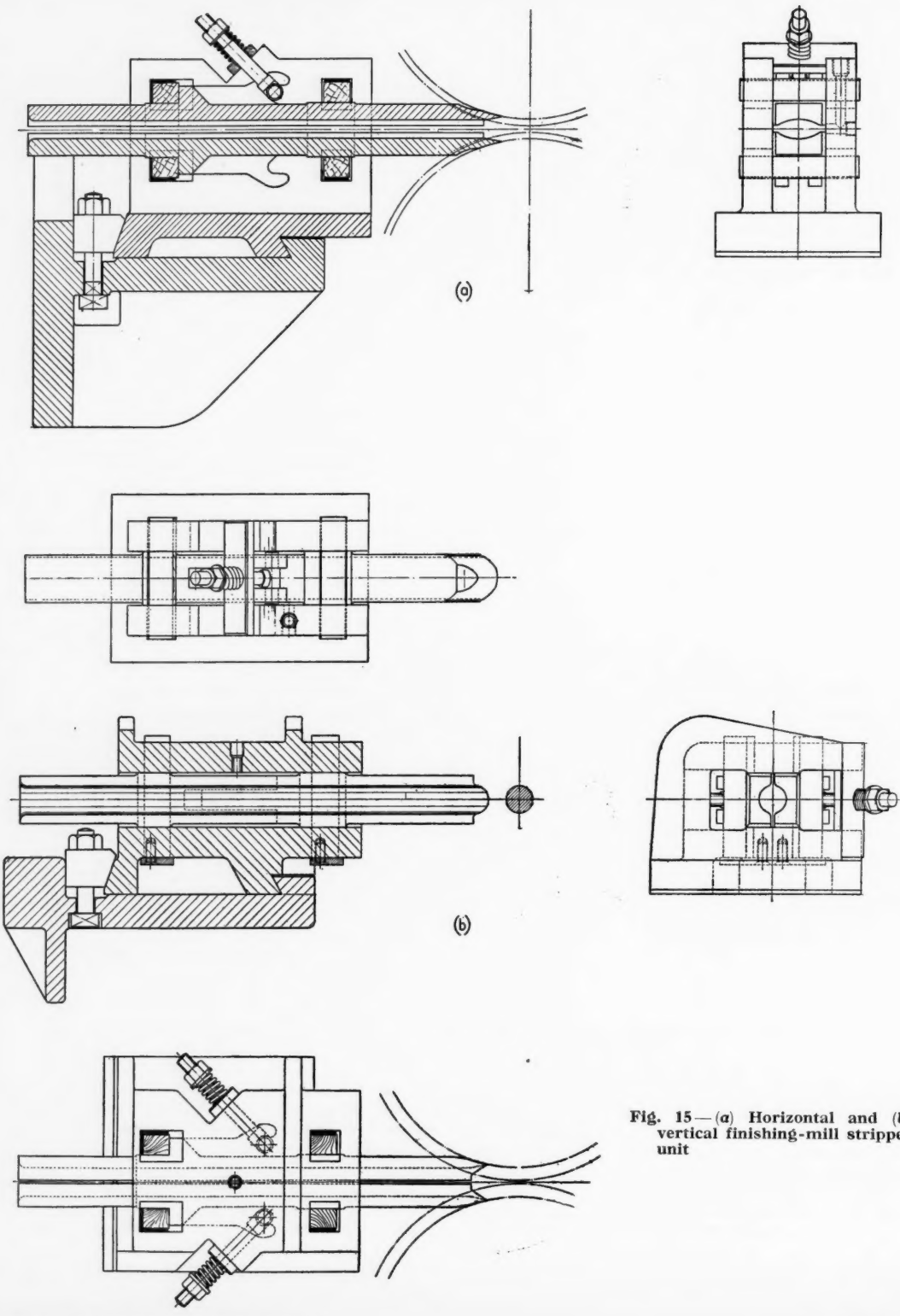

Fig. 15—(*a*) Horizontal and (*b*) vertical finishing-mill stripper unit

Figure 14*a* shows a guide which has a similar arrangement to that shown in Fig. 12, save that the guide frames and wedge gear are turned through 90°, whilst the top plate carries suitable clamp screws to lock the guide frames in position. Owing to the provision of the wedge gear on one side of the box, these assemblies are unsymmetrical, and frequent use is made of handed guide boxes to increase roll face availability.

Alternatively, as shown in Fig. 14*b*, the rollers may be supplied with a steeper groove form and fit over the shoulder of the section, but again contact must be made with the pass-produced form of the section. With this arrangement the rollers tend to become somewhat larger in diameter, which increases their inertia and results in an increase in the critical distance between the last roller and the roll bite. A further disadvantage is that the root of the roller groove restricts the clearance over the spread area of the bar, and there is always the inherent danger of an overfilled bar jamming in the guide, causing a cobble and possibly guide breakage. The provision of adequate clearance at this point tends to produce even larger rollers, whilst the large increase in guide tray centres for a small increase in section size tends to reduce the adaptability of the unit in relation to the number of sections handled.

In spite of these points, this type of guide can be very satisfactorily used on a mill with a limited range of products, *e.g.*, one devoted to the production of a few sizes of rounds used for subsequent wire-drawing operations.

Ball-bearings have been successfully used instead of the tapered roller types illustrated; where attempts are to be made to use very small rollers to guide small sections, the use of ball-bearings, with their reduced ratio of outside diameter to bore, may become essential. Plain bearings of the fabric type have been successfully used for guiding aluminium, where the heat conditions are not so severe, but the provision of a constant supply of water lubricant to the bearings results in a very complicated arrangement of lubrication holes. Self-lubricating heat-resisting carbon bushes have also been used and have functioned satisfactorily on the guiding of copper, where the heat conditions, whilst not as severe as when steel is being guided, are more arduous than for aluminium.

Where the initial expense can be justified, however, the use of anti-friction bearings is advisable, since to reduce friction at the axis of rotation of the roller also reduces slip of the bar at the roller groove and furthers the elimination of wear at this critical point. The use of unnecessarily large rollers can have a similar tendency to increase wear due to inertia drag. With good design and sound maintenance the replacement costs of ball- or roller-bearings will be less than those of normal bearings; they have the further advantage of retaining accurate roller location, particularly against thrust loads.

Roller equipment generally is a product of precision engineering, and this applies particularly to the entry guides; as such they must be treated with care and skill if they are to function satisfactorily. If the bar is to have smooth entry into the box and if all rollers are to have an equal share of the guiding duties, the roller grooves must be in perfect alignment. Therefore the grooves must be formed to accurate gauges locating from the matched outside diameter of the rollers. The grooves of all rollers in each roller tray must be perfectly central and it has been found advisable to use a special setting fixture to facilitate this operation.

The correct centre distance of the guide frames can only be determined by the use of a sample section bar; this is passed through the box, and the jacking screws are adjusted until the rollers have a slight clearance over the section to ensure free passage through the guide. With rollers designed to give contact points with a large angle of stability, sufficiently accurate control against rotation is maintained, giving lighter contact between bar and roller, reducing wear, and allowing the free passage of slightly oversized bars and especially of the critical nose end of the bar.

Accurate alignment of the assembled box with the roll pass is essential if good life is to be achieved. Even slight misalignment causes rapid and uneven wear of the rollers, increasing guide costs and reducing continuous service life. If the section bars previously referred to have one end reduced in form to agree with the following roll pass, correct alignment is assured when the bar located in the roller box freely enters the mill pass.

The supply of such additional guide-shop equipment naturally involves an increase in initial outlay, but the benefits derived are considerable. With well designed setting equipment and a planned assembly programme, unskilled labour can be successfully employed and the equipment can be very rapidly assembled. Furthermore, the increased continuous service life obtained from guaranteed accurate setting reduces guide costs and increases mill efficiency by reducing shut-down time.

Improved roller life has resulted from the application of a hard welded deposit of Stellite which is not materially affected by heat up to 1500° F. (825° C.) and is actually toughest at red heat.

The application of the Stellite deposit is a specialized operation. The roller blanks must be heated to about 1500° F. (825° C.) in an inert atmosphere which will prevent the oxidation of the base metal, and the whole weld must be kept in a state of flux until the deposit is completed, after which the roller is allowed to cool down slowly. Skill is required to avoid hair cracks and pin holes forming in the deposit, which will cause rapid failure of the guiding surface.

However, the results which have been obtained with this material, with an average life of 4000–8000 tons between regrinds, show it to be an economical proposition. By careful selection of the rollers for a particular task, these figures could be increased considerably. Thus if a newly dressed roller were first used for guiding one of the smallest sections in its range, the wear would be restricted to the bottom of the **V** sides, and the roller could again be used for a larger section without dressing; in this way it may be possible to double the normal production capacity of the roller.

Although roller guides have now been evolved which successfully control the small oval sections down to those producing 5 S.W.G. rounds, most plants in the

U.K. still use static guides for these small rod sizes. One successful design employs split guides in the form of a cartridge, capable of rapid mounting in matching bores of the mill breast beam.

The leading ovals producing these small round sizes are usually of very flat design to retain maximum control of the section against twist and at the same time to reduce twisting loads where inter-stand twisting is necessary, and the half guides are provided with close-fitting grooves of similar form. The design calls for a considerable amount of accurate machining to be carried out, and so they must be comparatively expensive. They are commonly of bronze, which, although it increases the initial cost, is claimed to reduce guide costs by avoiding breakages due to cobbles. The guides can therefore be re-dressed after use to guide a larger section, and the active life of each member is increased, whilst the high scrap value of the material offsets the high initial costs.

Some bar mills use static entry guides delivering to larger unstable reductions. Owing to the rapid wear of the guide profile, and to avoid cobbles caused by frictional resistance to the entry of the bar nose, they are often of the closing type. Half guides are used, one fixed and the other connected to a lever system, to close and grip the section immediately after entry into the mill. To avoid scratching and pick-up the guide members are commonly made of cast iron and suffer rapid wear, often requiring replacement twice per shift. The sizes of sections handled in this type of mill are such that they could be readily accommodated in roller guides, and it is thought that the latter will be substituted to an increasing extent.

HIGH-SPEED STRIPPER GUIDES

As previously described, the strippers of a straight-away continuous mill are responsible for the control of the bar between stands. Figures 15*a* and *b* show stripper units delivering straight bar from horizontal and vertical stands, respectively.

Timber breaker blocks are again used, the stripper being suitably adjusted for position by the use of shims. It has been found advantageous to grind the profile of the stripper to agree exactly with that of the pass. In this way the degree of control is directly related to the clearance between bar and stripper, and no jamming can occur as a result of overfilling. Furthermore, a series of sections produced from a single pass by increasing the roll gap can be guided on a single stripper assembly, adjustment of the shim packers setting the stripper blades to suit any particular section.

The feather edge at the nose of the stripper appears weak in comparison with those of the heavy roughing-mill strippers, but it stands up to the duty remarkably well. The use of matched roll diameters tends to produce a straight bar, whilst the provision of water jets to the roll bite tends to separate the bar from the pass surfaces, and reduces the tendency for bars to stick in the pass. Hence the stripping duty of the guide is considerably lightened and, with accurately formed stripper noses fitting closely to the pass surface to avoid fouling the bar nose, trouble is not likely to be encountered with the comparatively small sections these guides are designed to handle.

Very accurate control can be obtained by using these types of guide: the blades fitting closely around the section ensure twist-free delivery. With true straight-line delivery through the mills, the machined square faces of the stripper box and correct adjustment of the packing shims ensure accurate positioning into the following entry guide. With accurately aligned rolls the contact between bar and guiding surfaces is surprisingly light, the average production capacity of a stripper form being in the region of 1000–2000 tons before the stripper profile requires regrinding; this operation can be repeated several times.

The strippers illustrated are for operation in a continuous mill using alternate horizontal and vertical mill stands, which permits twist-free delivery from stand to stand. When twisting between consecutive horizontal stands at high speeds, plain twister strippers are often used. The comparatively light twisting loads required to twist the small sections do not seem to cause excessive wear.

The danger of surface irregularities which always arise when static twisting is undertaken may prove troublesome, especially when non-ferrous materials are being rolled. Under these conditions a roller twister stripper of the type shown in Fig. 10 will be found to give improved results in regard to guide life and surface finish.

Delivery of finished rod to the coiler spouts is often attained by using tube strippers, consisting of tube of suitable dimensions formed at the nose to fit the roll pass and retained in position by a system of timber breaker blocks as before.

Where tension rolling is carried out on the high-speed finishing stand, use is sometimes made of inter-stand tube guides, ensuring accurate delivery of the bar into the following entry guide. The degree of restriction incurred in this arrangement will probably increase the risk of guide breakage in the event of a cobble. In another arrangement used where the bar is twisted between stands, a considerable gap is allowed between twister stripper and entry guide to allow free escape of cobbled bars. Further protection is afforded to the entry guide unit by the provision of a second simple guide placed immediately before it, which, whilst normally allowing free passage of the bar between stands, will retain cobbled bars and hooked tail ends and prevent damage to the expensive entry guide units.

CONCLUSION

In the hand mill the effect of the efficiency of the guide equipment upon mill output is not easily apparent, since it is normally possible to carry out constant adjustments to guide and roll settings without appreciably affecting production, whilst the comparative simplicity of the equipment allows guide changes to be achieved very quickly.

In the continuous mill, however, it is impossible to make these adjustments without stopping production, and where mill output may average 50 tons/hr., the need for eliminating all unnecessary shut-down time

is self-evident. Only constant vigilance on the part of the mill management and crew, with the aim of eradicating unnecessary delays in roll and guide changes, can attain maximum plant efficiency, and the continual development of guide equipment to this end cannot be too strongly encouraged.

At the same time, the task of initially provisioning the plant with this vital equipment should be the responsibility of the mill manufacturer, working in close co-operation with the mill management and roll designer. The guide design should be undertaken at an early stage of the development of the plant. In this way any special feature can be readily incorporated into the design of the mill and rolls.

The increasing use of more complex guide units, particularly in the case of roller equipment, calls for a carefully planned and controlled guide shop. If guide costs are to be minimized, full use must be made of modern production techniques, and here again the mill manufacturers may be called upon to give advice in this specialized branch of engineering. The provision of production and assembly jigs and fixtures will result in considerably reduced guide costs and, by guaranteeing the accuracy of guide assemblies, will pay large dividends in increased mill output.

In attempting to reduce mill shut-down, various techniques have been evolved and have become accepted practice. Probably the most important of these is the use of change stands to effect rapid roll and programme changes. Spare mill housings are previously built up on dummy bedplates, with correctly adjusted rolls and all guide equipment assembled and lined up. As soon as production stops the affected stand is removed by crane and the replacement unit is substituted; with well trained mill crews this can result in a large saving in time.

Excessive loss of production due to guide failure can be insured against by having duplicate replacement assemblies readily available for substitution. The time taken to install the new guide can be reduced by maintaining a fixed height from the breast beam to the pass line through the box. This eliminates adjustment of the breast beam; the box merely requires horizontal adjustment along the latter to give correct alignment with the pass, the use of section sticks ensuring the accuracy of the latter operation when entry guides are being mounted.

Stripper boxes can be introduced in a similar way, the packers to the heel of the blade being ignored until the box is put into operation. The introduction of shims behind the timber thrust block will then adjust the nose of the blade close to the pass surface. The employment of this system entails the use of special height-gauge fixtures when guides are being assembled in the guide shop, but the saving of time on the mill floor justifies the incorporation of this additional equipment.

Preventive renewal of guides can be practised with advantage, and after a few months' experience this method can almost eliminate untimely shut-down due to guide failure. The nature of the shift working of the plant will to a great extent determine the desirable frequency of this operation. Thus a plant working a two-shift day may be most efficiently operated with a guide cycle of two shifts, even though the critical life of the equipment may be equivalent to a three-shift duty.

These, of course, are not the only factors controlling the efficient working of the plant. The layout and design of the mill will probably influence output more than any other factor, and without sound roll design the value of the finished product and the efficiency of the plant must suffer. Furthermore, perfect control of the bar is valueless if alignment of the mill rolls cannot be retained.

Nevertheless, the controlling influence which the guide equipment must have over the output of the whole plant cannot be ignored; when the cost of this equipment is compared with that of the plant, the benefits of a fuller utilization of the mill by a further exploitation of the guide equipment are obvious.

Acknowledgments

The author wishes to thank the Directors of The Brightside Foundry and Engineering Co., Ltd., for permission to prepare and publish this paper, and also his colleagues and friends within the industry who have assisted in its preparation.

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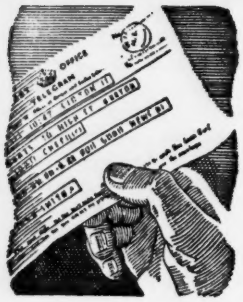


N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Annual General Meeting, 1955

The **Annual General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 27th and 28th April, 1955.** Full details of the programme will be given in a later issue of the *Journal*. The Dinner for Members will be held at Grosvenor House, Park Lane, on Wednesday, 27th April.

The Council

President-Elect—Sir CHARLES BRUCE-GARDNER, Bt., has been nominated by the Council for election as President, to take office at the Annual General Meeting in 1955.

Vice-President—Mr. D. F. CAMPBELL has been elected a Vice-President.

Member of Council—Mr. W. L. JAMES has been elected a Member of Council.

Honorary Member of Council—Mr. H. M. MORGAN has accepted an invitation to serve as an Honorary Member of Council during his term of office as President of the Cleveland Institution of Engineers.

NEWS OF MEMBERS

▶ Mr. J. CALLAGHAN has joined the Mufulira Copper Mines Ltd., N. Rhodesia, as a Learner Mine Official (Metallurgist).

▶ Professor G. CHAUDRON has been elected a Member of the Académie des Sciences.

▶ Mr. R. M. COOK has left the United Steel Companies Ltd., and has joined the Birmingham Laboratories of The Mond Nickel Co., Ltd.

▶ Mr. B. FRANCE has left the U.K. for Canada where he has joined the Gas Turbine Division of A. V. Roe Ltd., Ontario.

▶ Mr. F. J. HOUGHTON, B.Met., is now responsible for Technical Sales for Pickford, Holland and Co., Ltd., 381, Fulwood Road, Sheffield, 10. Since 1949 he has been Technical Manager of the Company's Works at Crook, Co. Durham.

▶ Dr. G. LUCAS has left the Department of Metallurgy, King's College, University of Durham, to take up an appointment in the Brown-Firth Research Laboratories.

▶ Mr. C. MCNAIR has resigned his appointment as Foundry Superintendent to Deloro Stellite Ltd., and has joined Millspaugh Ltd., Sheffield, as a metallurgist.

▶ Mr. H. F. MATON has relinquished his appointment as Chief Mechanical Engineer to Johnson, Matthey and Co., Ltd., to become General Manager of the Harlow Metal Co., Ltd.

▶ Mr. J. E. ROBERTS has left the British Welding Research Association to join the Research Department of Colvilles Ltd. at Motherwell.

▶ Monsieur CHARLES ROYER has left the Forges de l'Adour to become Superintendent of the Melting Department at the Aciéries de Firminy.

▶ Mr. H. H. SHEPHERD, who was until recently Metallurgical Projects Officer to the New South Wales branch of the Division of Industrial Development, Commonwealth Department of National Development, has returned to the U.K.

▶ Mr. N. SHEPPARD has left the Small Arms Factory, Lithgow, New South Wales.

▶ Mr. H. F. SPENCER has been appointed Chairman of the British Institute of Management.

▶ Mr. A. H. WATERFIELD has relinquished the post of Scientific Attaché at the British Embassy in Paris, and has returned to the U.K. to join the Department of Scientific and Industrial Research.

▶ Lt. Comd. G. W. WELLS, Chairman of the United Steel Structural Company and General Manager of the Appleby-Frodingham Steel Company, has been elected to the Board of the United Steel Companies Ltd.

Obituary

Lord CLYDESMUIR, Director of Colvilles Ltd., and National Governor for Scotland of the B.B.C., on 31st October, 1954, aged 60.

Mr. SETH SOMERS, O.B.E., J.P., Chairman of the Board of Walter Somers Ltd., Halesowen, on 9th November, 1954. Mr. Somers was elected a Member of the Institute in 1896.

CONTRIBUTOR TO THE JOURNAL

L. Cook, A.I.M., M.Inst.F.—Technical Adviser (Steelplant) to the Brazilian National Steel Company, Volta Redonda.

Mr. Cook received his technical education at Scunthorpe Technical School. He entered the laboratory of the Appleby-Frodingham Steel Co. as an Assistant Chemist, and in 1929 was transferred to the Open-Hearth Department as Assistant Manager. During this period he also received practical experience as a Sample Passer. In 1942 he was appointed Melting Shop Manager to the Turkish Iron and Steel Works at Karabuk. Four years later he joined the Brazilian National Steel Co., and was appointed to his present position shortly afterwards.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Operational Research Section

The Operational Research Section has issued the first Progress Report on the work of its Advisory Service Team, which was set up in October, 1953, with funds

supplied by a Conditional Aid Grant from the Mutual Security Agency. The object of this team is to carry out advisory work on problems of organization, handling, flow of materials, etc., in answer to specific requests from firms in the industry. Further summaries will be issued from time to time in accordance with the decision of the Operational Research Advisory Committee that a regular summary be issued of the subjects under investigation without referring to the names of the sponsors, so that other member firms having similar projects could, on request to B.I.S.R.A., be put in touch with the sponsor.

The method of operation of the Section is as follows: When a request for aid is received a member of the staff visits the works to discuss the problem, and if it is one in which the Advisory Service Team can help an agreement is made to begin work as soon as staff are available. If the problem is a technical one judged unsuitable for the team, it is referred to other Divisions of the Association where possible. Any member of the iron and steel industry may apply for the services of the Team.

Work has already been undertaken for both large and small firms, and falls under the following general categories: The assembly of materials for steel furnaces; the flow of materials and organization and layout of shops; production and quality control. In the first category a number of investigations have been concerned with achieving faster charging in order to increase output, and a number of cost estimates have been made in order to assess possible improvements. The flow of materials has been considered in relation to rolling mills and improvements have been sought without the installation of extra equipment. These studies involve the determination of the capacities of various processes in order to establish a proper balance between them. Investigations on production and quality control have evolved planning and production control systems with reduced paperwork and inspection systems based on simple control charts.

Eighth Chemists' Conference

Nearly 150 scientists from firms and organizations associated with the iron and steel industry attended the Eighth Chemists' Conference, held at 'The Hayes,' Swanwick, near Derby, on 12th and 13th October, 1954. Owing to the indisposition of Dr. Gregory, the Chair was taken at short notice by Mr. B. Bagshawe, who opened the proceedings with a review of the year's work of the Methods of Analysis Committee.

The first paper, given by Mr. R. A. Wells, dealt with chromatographic techniques for the separation of elements in steel analysis. It was followed by a survey of the analytical chemistry of boron presented by Mr. H. G. Short. Analytical methods for the determination of vanadium and titanium were dealt with respectively by Mr. L. E. Gardner and Mr. C. L. Grayson, and a report of an investigation on the determination of silica in slags and related materials was given by Mr. G. Padget. The analysis of slags by spectrography was described by Mr. A. Argyle. The concluding session was devoted to a paper by Mr. R. E. Lismer, in which methods for the separation and identification of inclusions in steel were outlined.

NEWS OF SCIENCE AND INDUSTRY

Postgraduate Courses in Science

The Department of Extra-Mural Studies of the University of Liverpool is holding four post-graduate courses during the Spring Term of 1955, on the following subjects: Refractories, an introduction to servomechanisms, microbiology, and the design and analysis of scientific experiments. Further details are obtainable from the Director of Extra-Mural Studies at 9 Abercromby Square, Liverpool, 7, and applicants are advised to enrol for the courses not later than the first week in January.

Refractories in Metal Industries

A Symposium on "*Recent Trends in the Field of Production, Practice and Research on Refractories Used in Metal Industries*" will be held at the National Metallurgical Laboratory, Jamshedpur, India, on 19th–21st January, 1955. The Symposium will cover the preparation of refractories, equipment, and recent trends in the production of alumino-silicate, silica, and basic refractories.

Indian Institute of Metals

The Eighth Annual General Meeting of the Indian Institute of Metals will be held in Jamshedpur on 23rd–25th January, 1955. A metallographic exhibition will be held in conjunction with the meeting.

Powder Austrian Seminar

The Second International Plansee Seminar "*De Re Metallica*" will take place in Reutte, Tyrol, Austria, from 20th to 23rd June, 1955. These dates have been chosen to make it possible for participants in the Joint Metallurgical Societies' Meeting in Europe to attend.

Like the First Seminar held in 1952, the Second will be devoted to problems of powder metallurgy and the general topic will be "*High-Temperature Materials Produced by Powder Metallurgy.*" A number of American and European specialists, well-known in the field of powder metallurgy, have accepted invitations to speak.

Spanish Iron and Steel Institute

The Third General Assembly of the Spanish Iron and Steel Institute will be held in Barcelona, Madrid, and other parts of Spain on 20th June–2nd July, 1955. The First and Second General Assemblies of the Institute were held in 1947 and 1951, and it has been decided to hold the Opening Session of the Third Assembly in Barcelona on 20th June to coincide with the International Industries Fair being held in Barcelona on that date.

B.W.R.A. Open Days

The Metallurgical Laboratories of the British Welding Research Association held 'Open Days' on 23rd and 24th November, 1954. The main part of the Exhibition was devoted to the Association's work on steels and the light alloys; demonstrations included a dilatometric method for the assessment of weldability, and the use of the self-adjusting-arc welding process. Research on hot-cracking, intergranular cracking, the determination of hydrogen, heat flow, and dilution effects was also on view. The Exhibition enabled visitors to see some part of the work of the Liaison Department, the Library, and the Information Services, and other *ad hoc* research activities.

Owing to limitations of space and time, many people who wished to visit the laboratories had to be turned away and it is therefore hoped that a similar event may be held in about two years' time.

Industrial Publications Received

▶ "*Forgings,*" a fully illustrated booklet giving details of the manufacture and processing of forgings at the English Steel Corporation Ltd. Copies are available, free of charge, on request to the Corporation.

▶ Brochure on 'Crusilite' electric furnace elements—Publication No. TD6—Morgan Crucible Co., Ltd.

▶ Brochure on the 'Rollabench,' a device for providing extra bench space—Leaflet No. 130/54—Shandon Scientific Co., Ltd.

▶ "*Research at Sunbury*," an illustrated booklet produced by the Anglo-Iranian Oil Co., Ltd., gives details of the Company's main research station at Sunbury-on-Thames, and describes work carried out there.

▶ Palladium Leak Detector Model 3A and associated pumping units — Publication No. D. 141/2 — Vapour 'Speedivac' Pumps. Section 1: Diffusion pumps—Publication No. B. 118/1—W. Edwards and Co. (London), Ltd.

▶ Brochure on the 'Kandu' track—Publication No. KAN 654—Geo. W. King Ltd.

▶ Brochure on Pyruma and Aluma Fire Cements and Siluma Hot-Patching Cement—J. H. Sankey and Son Ltd.

▶ Brochure on the 'Stanrun' light overhead chain conveyor—Geo. W. King Ltd.

▶ "*How Automatic Can We Get?*"—Excerpts from a talk on automatic control, given by the President of the Brown Instruments Division of Minneapolis-Honeywell Regulator Co.—Honeywell-Brown Ltd.

▶ Electron microscopes—Gives details of 75-kV. and 100-kV. electron microscopes and a shadow-casting unit—Ref. No. PX.4059—Philips Electrical Ltd.

▶ Brochure on acid-resisting cement, giving details of its properties and directions for use—J. H. Sankey and Son, Ltd.

▶ "*Research, Development, Achievement*" is a pictorial survey of recent activities of the General Electric Co., Ltd., in selected fields of endeavour, including power control and distribution, rectifier research, and trends in electronics.

CORRIGENDUM

Roll Makers' Association

It was stated on p. 187 of the October, 1954, issue of the *Journal* that Mr. F. Trehearne Thomas had been appointed Chairman of the Roll Makers' Association of Great Britain. The name should have read Mr. F. H. Treherne Thomas.

DIARY

4th Jan.—Swansea and District Metallurgical Society—"*Instrumentation in the Making and Processing of Steel*," by S. S. Carlisle—Central Library, Swansea, 7.0 p.m.

10th Jan.—Lincolnshire Iron and Steel Institute—"*Some of the Problems of Design of Seraphim Plant*," by I. M. Kemp—North Lindsey Technical College, Kingsway, Scunthorpe, 7.30 p.m.

10th Jan.—Cleveland Institution of Engineers—"*The Installation and Layout of New Slabbing and Billet Mills at Consett*," by A. Marshall—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 p.m.

11th Jan.—Sheffield Metallurgical Association—Discussion on Open-Hearth Furnaces: Walls, Ends, and Ports—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 p.m.

12th Jan.—North Wales Metallurgical Society—"*Sintering*," by R. Wild—County Primary School, Plymouth Street, Shotton, Chester, 7.15 p.m.

12th Jan.—Manchester Metallurgical Society—Conversazione—Metallurgy Department, University of Manchester, 6.30 p.m.

13th Jan.—Ebbw Vale Metallurgical Society—"*Some Aspects of the Basic Bessemer Process*," by G. Players, and "*Electric Power Supply in Iron and Steel Works*," by E. R. Davies—Lecture Hall, Richard Thomas and Baldwins Ltd., Ebbw Vale, 7.15 p.m.

13th Jan.—Staffordshire Iron and Steel Institute—"*Some Factors Affecting Spring Design*," by W. R. Berry—West Bromwich Technical College, 7.30 p.m.

13th Jan.—Institute of Fuel—"*Integration in the Iron and Steel Industry*," by W. F. Cartwright—Institution of Civil Engineers, Great George Street, London, S.W.1, 5.30 p.m.

17th Jan.—Sheffield Society of Engineers and Metallurgists (Joint meeting with the Sheffield Metallurgical Association)—"*Metallurgical Research in the Electrical Industry*," by I. Jenkins—University Building, St. George's Square, Sheffield, 7.30 p.m.

19th Jan.—Newport and District Metallurgical Society—Works visit to Bristol Aeroplane Co., Ltd.

21st Jan.—Staffordshire Iron and Steel Institute—Annual Dinner—Wulfrun Hall, Wolverhampton.

26th Jan.—Manchester Metallurgical Society—"*Cathodic Protection*," by W. F. Higgins—Lecture Room, Central Library, Manchester, 6.30 p.m.

27th Jan.—Institute of Metals (Birmingham Local Section)—"*Diffusion in Metals*," by A. D. Le Claire—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 p.m.

27th Jan.—North East Metallurgical Society—"*The Manufacture and Properties of Some Heavy Forgings*," by H. H. Burton—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 7.15 p.m.

1st Feb.—Sheffield Metallurgical Association—"*Recent Advances in the Radiography of Steel*," by H. S. Pieser—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 p.m.

3rd Feb.—Staffordshire Iron and Steel Institute—"*Work Study Applied to Steel Production*," by T. U. Matthew—Star and Garter Royal Hotel, Wolverhampton, 7.30 p.m.

7th Feb.—Cleveland Institution of Engineers—"*Iron Making at Skinningrove*," by R. Kingston—Cleveland Scientific and Technical Institution, Corporation Road, Middlesbrough, 6.30 p.m.

TRANSLATION SERVICE

(The previous announcement was made in the December 1954 issue of the *Journal*, p. 399).

Translations Available

No. 493 (German). A. Keil: "Should One Use Solid or Segmented Resin Bearings in Rolling Mills?" (*Die Technik*, 1953, vol. 8, Sept., pp. 609–612).

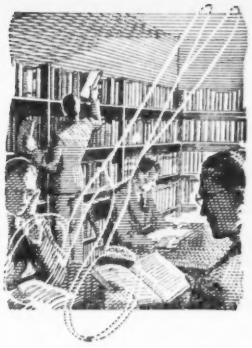
No. 496 (German; also in Swedish). E. Johannson: "Experiences with the Production of Large Forging Ingots Weighing up to 35 Tons." (*Radex Rundschau*, 1954, No. 4–5, pp. 107–121).

No. 497 (German). H. Kosmider, H. Neuhaus, and H. Kratzenstein: "The Waste-Gas Conditions in the Basic Bessemer Plant When Using Various Refining Gases." (*Stahl und Eisen*, 1954, vol. 74, Aug. 12, pp. 1045–1053).

Translation in Course of Preparation

(Swedish). C. G. Carlsson and L. Danielsson: "Direct-Reading Spectrographic Determination of Phosphorus in Steel and Iron Ore." (*Jernkontorets Annaler*, 1954, vol. 138, No. 7, pp. 383–403).

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



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ABBREVIATIONS AND LIST OF PERIODICALS EXAMINED BY THE ABSTRACTING SERVICE

Abhandlungen der Braunschweigischen wissenschaftlichen Gesellschaft (Brunswick)
Acciaio Inossidabile (Milan)
Acero y Energia (Barcelona)
Aciers Fins et Speciaux Français (Paris)
Acta Crystallographica (London)
Acta Metallurgica (Toronto)
Acta Physica Polonica (Warsaw)
Acta Polytechnica (Stockholm)
Acta Technica (Budapest)
Advancement of Science (London)
Advances in Physics (London)
Aeroplane (London)
Aircraft Engineering (London)
Aircraft Production (London)
Alloy Castings Bulletin (New York)
Alloy Metals Review (Widnes)
Alluminio (Milan)
Aluminium (Düsseldorf)
Aluminium Development Association, Information Bulletin (London)
American Foundryman (Chicago)
American Foundrymen's Society, Preprint (Chicago)
American Institute of Mining and Metallurgical Engineers (New York)
Blast Furnace and Raw Materials Committee
Proceedings Electric Furnace Steel Conference
Proceedings National Open-Hearth Committee
Proceedings Symposia Series
American Iron and Steel Institute (New York)
Annual Statistical Report
Contributions to the Metallurgy of Steel
Steel Products Manual
American Journal of Physics (New York)
American Journal of Science (New Haven, Conn.)
American Society for Metals, Preprint (Cleveland, Ohio)
American Society for Testing Materials (Philadelphia)
Preprint
Special Technical Publication
Anais da Academia Brasileira de Ciencias (Rio de Janeiro)
Anais Associacao Brasileira de Quimica (Sao Paulo)
Anales de la Asociacion Química Argentina (Buenos Aires)
Anales de la Real Sociedad Española de Fisica y Química (Madrid)
Anales de Mecanica y Electricidad (Madrid)
Analyst (London)
Analytica Chimica Acta (New York and Amsterdam)
Analytical Chemistry (Washington)
Annales des Mines (Paris)
Annales de la Société Scientifique de Bruxelles (Brussels)
Annual Proceedings of the Sheet and Strip Metal Users' Technical Association (London)
Annual Report of the Smithsonian Institution (Washington)
Annual Review of Physical Chemistry (Stanford, California)
Anvil (Sheffield)
Applied Mechanics Reviews (New York)
Applied Research Laboratories, Reports (Glendale, Calif.)
Applied Scientific Research (The Hague)
Archiv für das Eisenhüttenwesen (Düsseldorf)
Archiwum Gornictwa i Hutnictwa (Warsaw)
Arkiv för Fysik (Stockholm)
Arkiv för Kemi (Stockholm)
Arkiv för Mineralogi och Geologi (Stockholm)
Arts et Manufacturers (Paris)
Atomics (London)
Atti della Accademia Nazionale dei Lincei. Rendiconti della Classe di Scienze Fisiche, Matematiche e Naturali (Rome)
Australasian Engineer (Sydney)
Australasian Plating and Finishing (Melbourne)
Australian Journal of Applied Science (Melbourne)
Australian Journal of Chemistry (Melbourne)
Australian Journal of Physics (Melbourne)
Australian Machinery (Sydney)
Automobile Engineer (London)

B.C. Professional Engineer (Vancouver)
B.H.P. Review (Melbourne)
Ball Bearing Journal (Luton)
Battelle Technical Review (Columbus, Ohio)
Beama Journal (London)
Bell Laboratories Record (New York)
Bell System Technical Journal (New York)
Bell Telephone Laboratories Technical Publication (New York)
Bell Telephone Magazine (New York)
Berg- und hüttenmännische Monatshefte (Vienna)
Bibliographical Bulletin of Welding (Paris)
Blad for Bergshandteringens Vänner (Stockholm)
Blast Furnace and Steel Plant (Pittsburgh)

LIST OF PERIODICALS

Boletim da Associação Brasileira de Metais (São Paulo)
Boletim da Associação Química do Brasil (Rio de Janeiro)
Boletim da Sociedade Geológica de Portugal (Oporto)
Boletim do INT (Rio de Janeiro)
Boletin Minero e Industrial (Bilbao)
Brennstoff–Warme–Kraft (Dusseldorf)
British Cast Iron Research Association, Journal of Research and Development (Birmingham)
British Coal Utilisation Research Association, Monthly Bulletin (London)
British Coke Research Association, Technical Papers (London)
British Dental Journal (London)
British Electrical and Allied Industries Research Association, Reports (London)
British Engineering (London)
British Iron and Steel Federation, Monthly Statistical Bulletin (London)
British Iron and Steel Research Association, Reports (London)
British Journal of Applied Physics (London)
British Steelmaker (London)
British Welding Journal (London)
Brown-Boveri Review (Baden)
Bulletin de L'Académie Polonaise des Sciences Classe Quatrième (Warsaw)
Bulletin of the American Ceramic Society (Columbus, O.)
Bulletin, American Society for Testing Materials (Philadelphia)
Bulletin of the British Scientific Instrument Research Association (London)
Bulletin, British Steel Founders' Association (Sheffield)
Bulletin de Cercle d'Etudes des Métaux (St. Etienne)
Bulletin and Foundry Abstracts of the British Cast Iron Research Association (Birmingham)
Bulletin of the Institute of Metal Finishing (London)
Bulletin of the Institution of Metallurgists (London)
Bulletin of the Institution of Mining and Metallurgy (London)
Bulletin of Ohio State University Engineering Experiment Station (Columbus, O.)
Bulletin of the School of Mines and Metallurgy, University of Missouri (Minneapolis)
Bulletin des Sociétés Chimiques Belges (Brussels)
Bulletin of the University of Wisconsin, Engineering Experiment Station Series
Canada Department of Mines and Technical Surveys, Mines Branch, Research and Special Projects Reports (Ottawa)
Canadian Journal of Chemistry (Ottawa)
Canadian Journal of Physics (Ottawa)
Canadian Journal of Technology (Ottawa)
Canadian Metals (Toronto)
Canadian Mining Journal (Quebec)
Canadian Mining and Metallurgical Bulletin (Montreal)
Calore (Milan)
Centre de Documentation Sidérurgique, Circulaires d'Informations Techniques (Paris)
Ceramics (Leighton Buzzard)
Chaleur et Industrie (Paris)
Chartered Mechanical Engineer (London)
Chemical Age (London)
Chemical Engineering (New York)
Chemical Engineering and Mining Review (Melbourne)
Chemical and Engineering News (Washington)
Chemical Engineering Progress (New York)
Chemical & Process Engineering (London)
Chemické Listy (Prague)
Chemisch Weekblad (Amsterdam)
Chemist-Analyst (Phillipsburg, N.J.)
Chemistry and Industry (London)
Chimica e Industria (Milan)
Chimie Analytique (Paris)
Chimie et Industrie (Paris)
Ciencia y Tecnica de la Soldadura (Madrid)
Circular of the National Bureau of Standards (Washington)
Circular of Ohio State University Engineering Experiment Station (Columbus)
Claycraft (London)
Coke and Gas (London)
Coke Review (London)
Collection of Czechoslovak Chemical Communications (Prague)
Colliery Guardian (London)
Colonial Geology and Mineral Resources (London)
Colorado School of Mines, Quarterly (Golden, Colorado)
Commonwealth Engineer (Melbourne)
Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences (Paris)
Congrès du Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique (Paris)
Corrosion (Houston, Texas)
Corrosion et Anti-Corrosion (Paris)
Corrosion Prevention and Control (London)
Corrosion Technology (London)
Costruzioni Metalliche (Milan)
Coventry Engineering Society Journal (Coventry)

Dansk Teknisk Tidsskrift (Copenhagen)
Demag News (Duisburg)
Discussions of the Faraday Society (London)
Documentation Métallurgique (Paris)
Doklady Akademii Nauk S.S.S.R., Comptes Rendus de L'Academie des Sciences à Leningrad (Moscow)
Draht (English edition) (Coburg)
Draht (German edition) (Coburg)
Dyna (Barcelona)

E.S.C. News (Sheffield)
Echo des Mines (Paris)
Edgar Allen News (Sheffield)
Edison Electric Institute Bulletin (Philadelphia)
Eidgenossische Materialprüfungs- und Versuchsantalt für Industrie, Bauwesen und Gewerbe, Berichte (Zürich)
Electrical Engineer and Merchandiser (Melbourne)
Electrical Journal (London)
Electrical Power Engineer (London)
Electrical Review (London)
Electrical Times (London)
Electronic Engineering (London)
Electroplating (London)
Elektrotechniski Vestnik (Ljubljana, Yugoslavia)
Elektrowärme Technik (Mindelheim)
Elliott Journal (London)
Endeavour (London)
Engenharia, Mineração e Metalurgia (Rio de Janeiro)
Engineer (London)
Engineer and Foundryman (Braamfontein, Johannesburg)
Engineering (London)
Engineering and Boiler House Review (London)
Engineering Inspection (London)
Engineering Journal (Montreal)
Engineering and Mining Journal (New York)
Engineering Research Bulletin, University of Michigan (Ann Arbor)
Engineers' Digest (London)
English Electric Journal (Stafford)
Escher-Wyss News (Zürich)
Experientia (Basle)

First Iron Works Association, Gazette (Saugus, Mass.)
Fonderia Italiana (Milan)
Fonderie (Paris)
Forschung auf dem Gebiete des Ingenieurwesens (Düsseldorf)
Foundry (Cleveland)
Foundry and Metal Treating (Sydney)
Foundry Trade Journal (London)
Freyn Design (Chicago)
Fuel (London)
Fuel Economy Review (London)
Fuel Society Journal (Sheffield)

G.E.C. Journal (London)
G.E.C. Telecommunications (Coventry)
Galvano (Paris)
Gas Research Board Communications (Beckenham)
Gas Times (Watford)
Gas World (London)
Gazzetta Chimica Italiana (Rome)
General Motors Engineering Journal (Detroit)
Génie Civil (Paris)
Geologiska Föreningens Förhandlingar (Stockholm)
Giesserei (Düsseldorf)
Gjuteriet (Stockholm)
Glückauf (Essen)
Government Mechanical Laboratory Bulletin (Tokyo)

Hutnické Listy (Prague)
Hutnik (Prague)
Hutnik (Poland)

IVA Ingeniörs Vetenskaps Akademien (Stockholm)
Illinois University Engineering Experiment Station (Urbana)
Circular
Bulletin
Indian Journal of Physics (Calcutta)
Industria y Química (Buenos Aires)
Industrial Chemist (London)
Industrial and Engineering Chemistry (Washington)
Industrial Finishing (Leighton Buzzard)
Industrial Gas (Leighton Buzzard)
Industrial Heating (Pittsburgh)
Industrial Heating Engineer (London)
Industrie Nationale (Paris)
Ingegneria Meccanica (Milan)

Ingenieria e Industria (Buenos Aires)
Ingeniörs Vetenskaps Akademien, Handlingar (Stockholm)
Institut pour l'Encouragement de la Recherche Scientifique, Comptes Rendus de Recherches (Brussels)
Institute of British Foundrymen, Advance Copies (Manchester)
Institute of Fuel, Advance Copies (London)
Institute of Petroleum, I.P. Review (London)
Institution of Gas Engineers, Communications (London)
Instituto del Hierro y del Acero (Madrid)
Instituto de la Soldadura, Publicacíon (Madrid)
Instituto Sperimentale Dei Metalli Leggeri, Relazione Annuale (Milan)
Instituto Nacional del Carbon Boletin Informativo (Oviedo)
Instituto Nacional de Tecnologia Boletin (Rio de Janeiro)
Instrument Engineer (Luton)
Instrument Practice (London)
Instruments in Industry (London)
Iron Age (New York)
Iron and Coal Trades Review (London)
Iron and Steel (London)
Iron and Steel Engineer (Pittsburgh)
Iron and Steel Institute, Special Reports (London)
Izvestiya Akademii Nauk S.S.S.R., Otdelenie Khimcheskikh Nauk (Moscow)
Izvestiya Akademii Nauk, S.S.S.R., Otdelenie Teknicheskikh Nauk (Moscow)
Izvestiya Akademii Nauk S.S.S.R., Seriya Fizicheskaya (Moscow)

Jernindustri (Oslo)
Jernkontorets Annaler (Stockholm)
Journal of the American Ceramic Society (Columbus, Ohio)
Journal of the American Chemical Society (Washington, D.C.)
Journal of the American Society of Naval Engineers (Washington, D.C.)
Journal of the American Water Works Association (New York)
Journal of the American Zinc Institute (New York)
Journal of Applied Chemistry (London)
Journal of Applied Mechanics (New York)
Journal of Applied Physics (New York)
Journal of the Birmingham Metallurgical Society (Birmingham)
Journal of the British Institution of Radio Engineers (London)
Journal of the British Shipbuilding Research Association (London)
Journal of the Chemical, Metallurgical and Mining Society of South Africa (Johannesburg)
Journal of Chemical Physics (New York)
Journal of the Chemical Society (London)
Journal de Chimie Physique (Paris)
Journal of Dental Research (Baltimore)
Journal of the Electrochemical Society (Baltimore)
Journal du Four Electrique (Paris)
Journal of the Franklin Institute (Lancaster, Pa.)
Journal of the Indian Chemical Society (Calcutta)
Journal of the Institute of Australian Foundrymen (Melbourne)
Journal of the Institute of Fuel (London)
Journal of the Institute of Metals (London)
Journal of the Institute of Petroleum (London)
Journal of the Institution of Automotive and Aeronautical Engineers (Melbourne)
Journal of the Institution of Civil Engineers (London)
Journal of the Institution of Engineers, Australia (Sydney)
Journal of the Institution of Heating and Ventilating Engineers (London)
Journal of the Institution of Locomotive Engineers (London)
Journal of the Institution of Production Engineers (London)
Journal of The Iron and Steel Institute (London)
Journal of Mechanical Laboratory (Tokyo)
Journal of the Mechanics and Physics of Solids (London)
Journal of Metals (New York)
Journal of Nuclear Energy (London)
Journal of the Optical Society of America (New York)
Journal of Petroleum Technology (Dallas, Texas)
Journal of the Physical Society of Japan (Tokyo)
Journal de Physique et le Radium (Paris)
Journal of the Royal Institute of Chemistry (London)
Journal and Proceedings of the Royal Society of New South Wales (Sydney)
Journal and Record of Transactions of the Junior Institution of Engineers (London)
Journal of Research of the National Bureau of Standards (Washington, D.C.)
Journal of the Royal Aeronautical Society (London)
Journal of the Royal Artillery (London)
Journal of the Royal Institute of British Architects (London)
Journal of the Royal Microscopical Society (London)
Journal of the Royal Society of Arts (London)
Journal of the Royal Statistical Society (London)
Journal of Scientific Instruments (London)
Journal of Scientific and Industrial Research (New Delhi)
Journal of the Scientific Research Institute (Tokyo)
Journal of the Society of Glass Technology (Sheffield)
Journal of the South African Institution of Mechanical Engineers (Johannesburg)
Journal and Transactions of the Society of Engineers (London)
Journal of the West of Scotland Iron and Steel Institute (London)

Kohászati Lapok (Budapest)
Kyoto University, Engineering Research Institute, Technical Reports (Kyoto)

Laboratoria N.V. Philips' Gloeilampfabrieken, Separaat (Eindhoven)
Lastechniek (The Hague)
Light Metal Age (Chicago)
Light Metals (London)
Liteĭnoe Proizvodstvo (Moscow) [Foundry Production]
Lithgow Journal (Glasgow)

Machine Design (Cleveland, Ohio)
Machine Shop Magazine (London)
Machinery (Brighton)
Machinist (London)
Manchester Association of Engineers, Preprints (Manchester)
Maschinenbau und Wärmewirtschaft (Vienna)
Maschinenwelt und Elektrotechnik (Vienna)
Materials and Methods (New York)
Mechanical Engineering (New York)
Mechanical Handling (London)
Mechanical World (London)
Memoirs of the Faculty of Engineering Kyoto University (Kyoto)
Memoirs of the Faculty of Engineering Kyushu University (Fukuoka)
Memoirs of the Faculty of Technology, Tokyo Metropolitan University (Tokyo)
Memoirs of the Geological Survey of India (Calcutta)
Mémoires de la Société des Ingénieurs Civils de France (Paris)
Mémorial de l'Artillerie Française (Paris)
Metal Age (London)
Metal Bulletin (London)
Metal Finishing (New York)
Metal Industry (London)
Metal Progress (Cleveland, Ohio)
Metal Treating (New Rochelle, N.Y.)
Metal Treatment and Drop Forging (London)
Metalen (The Hague)
Metall (Berlin)
Metalloberfläche (Munich)
Metallurgia (Manchester)
Metalurgia y Electricidad (Madrid)
Metallurgia Italiana (Milan)
Métallurgie et la Construction Mécanique (Paris)
Metallurgie und Giesserei Technik (Berlin)
Métaux–Corrosion–Industries (Paris)
Metropolitan Vickers Gazette (Manchester)
Michigan University (Ann Arbor) Engineering Research Bulletins Engineering Research Circulars
Microtecnic (Lausanne)
Mine and Quarry Engineering (London)
Mineralogical Magazine (London)
Mines Magazine (Denver, Colo.)
Mining, Electrical and Mechanical Engineer (Manchester)
Mining Engineering (New York)
Mining Journal (London)
Mining Magazine (London)
Mitteilungen aus dem Max-Planck-Institut für Eisenforschung (Düsseldorf)
Modern Foundry (Melbourne)
Modern Metals (Chicago)
Murex Review (Rainham, Essex)

National Physical Laboratory, Reports (Teddington)

LIST OF PERIODICALS

National Science Foundation Translations (Washington)
Nature (London)
New Zealand Engineering (Wellington)
New Zealand Journal of Science and Technology (Wellington)
Nickel Bulletin (London)
Nippon Kinzoku Gakkai-Si (Sendai)
Non-Destructive Testing (Evanston, Ill.)
Norsk Geologisk Tidsskrift (Oslo)

Oil Engine and Gas Turbine (London)
Operational Research Quarterly (London)
Optima (Johannesburg)
Osaka City University, Journal of the Institute of Polytechnics (Osaka)
Osaka University, Faculty of Engineering Technology Reports (Osaka)
Ossature Métallique (Brussels)
Overseas Engineer (London)

Paliva (Prague)
Peintures, Pigments, Vernis (Paris)
Philippine Geologist (Manila)
Philips Research Reports (Eindhoven)
Philips Technical Review (Amsterdam)
Philosophical Magazine (London)
Philosophical Transactions of the Royal Society (London)
Physical Review (New York)
Planseeberichte für Pulvermetallurgie (Reutte, Tyrol)
Plating (Jenkintown, Pa.)
Powder Metallurgy Bulletin (Yonkers N.Y.)
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Prace Instytutow Ministerstwa Hutnictwa (Poland)
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Proceedings of the Annual Convention of the American Electroplaters' Society (Jenkintown, Pa.)
Proceedings, Australasian Institute of Mining and Metallurgy (Melbourne)
Proceedings of the Australian Institute of Metals (Melbourne)
Proceedings of the Cambridge Philosophical Society (London)
Proceedings, Chemical Engineering Group (London)
Proceedings, Diesel Engine Users' Association (London)
Proceedings of the Durham Philosophical Society (Durham)
Proceedings of the Ebbw Vale Metallurgical Society (Ebbw Vale)
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Proceedings of the Institute of Australian Foundrymen (Melbourne)
Proceedings of the Institute of British Foundrymen (Manchester)
Proceedings of the Institution of Electrical Engineers (London)
Proceedings, Institution of Mechanical Engineers (London)
Proceedings of the Institution of Mechanical Engineers, Automobile Division (London)
Proceedings of the Japan Academy (Tokyo)
Proceedings of the Lincolnshire Iron and Steel Institute (Scunthorpe)
Proceedings, Metal Powder Association (New York)
Proceedings, Natural Gas Department of the American Gas Association (New York)
Proceedings of the Physical Society (London)
Proceedings of the Royal Canadian Institute (Toronto)
Proceedings of the Royal Institution of Great Britain (London)
Proceedings of the Royal Society (London)
Proceedings of the Royal Society of Edinburgh (Edinburgh)
Proceedings of the Society of Experimental Stress Analysis (Cambridge, Mass.)
Proceedings of the South Wales Institute of Engineers (Cardiff)
Proceedings of the Staffordshire Iron and Steel Institute (Walsall)
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Product Finishing (London)
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Quarterly Journal of the Geological, Mining, and Metallurgical Society of India (Calcutta)
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Records of the Geological Survey of India (Calcutta)
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Refractories Journal (London)
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Revista de Quimica Industrial (Rio de Janeiro)
Revue de l'Aluminium (Paris)
Revue de la Faculté des Sciences de l'Université d'Istanbul
Revue Générale de Mécanique (Paris)
Revue de l'Industrie Minérale (St. Etienne)
Revue de Métallurgie (Paris)
Revue des Produits Chimiques (Paris)
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Revue du Nickel (Paris)
Revue de la Société Royale Belge des Ingenieurs et des Industriels (Bruxelles)
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Teknisk Tidskrift (Stockholm)
Teknisk Ukeblad (Oslo)
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Tidsskrift for Kjemi, Bergvesen og Metallurgi (Oslo)
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Transactions of the American Society of Mechanical Engineers (New York)
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Transactions of the Royal Canadian Institute (Toronto)
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Varilna Tehnika (Ljubljana)
Värmländska Bergsmanneföreningens Annaler (Filipstad, Sweden)
Vestnik Mashinostroenniya (Moscow)
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Welding Research Council, Welding Research Council Bulletin Series (New York)
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Werkszeitung (Vienna)
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Wire Industry (London)
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Zeitschrift für Erzbergbau und Metallhüttenwesen (Stuttgart)
Zeitschrift für Metallkunde (Stuttgart)
Zeitschrift des Vereines deutscher Ingenieure (Düsseldorf)
Zhurnal Fizicheskoi Khimii (Moscow)
Zhurnal Prikladnoi Khimii (Moscow)
Zhurnal Tekhnicheskoi Fiziki (Moscow)

ABSTRACTS

MINERAL RESOURCES

Quebec-Labrador Iron Ore Potential Dwarfs Mesabi Range. W. H. Durrell. (*J. Met.*, 1954, **6**, Apr., 452–454). The author describes the location and extent of the Quebec-Labrador iron-ore deposits, and compares their potentialities with those of the Mesabi Range. The arrangements made for mining and transportation are also discussed.—G. F.

Yugoslavia—Potential Mineral Giant. (*Min. Eng.*, 1954, **6**, May, 490–493). The post-war Yugoslavian economy is conscious of the need for industrial development; exploration has shown the presence of great mineral wealth. Details are given of the estimated reserves of various coals, petroleum, oil shale, iron ore, manganese ore, chromium ore, molybdenum, nickel, cobalt and tungsten ore, lead-zinc ore, copper ore, bauxite, antimony, mercury, pyrite, gold, and silver. Some particulars of the mining operations are also given.—K. E. J.

Dense Martite-Hematite Ores from the Sagsaganskii Region of the Krivoi Rog. Ya.N. Belevtsev and R. P. Dubinkina. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **96**, (2), 355–357). [In Russian]. Krivoi Rog ores are mainly soft, but recently considerable deposits of dense ores were found. A description of these dense Martite-Hematite ores and their origin is given.—V. G.

Brazil's Iron and Manganese Ores. O. H. Ödman. (*Tekn. Tidskr.*, 1954, **84**, June 8, 525–532). [In Swedish]. Brazilian ore resources are reviewed and an account is given of the nature and geological characteristics of the iron and manganese ore deposits in the Minas Gerais, Morro do Urucum, and Serva do Navio areas.—G. G. K.

ORES—MINING AND TREATMENT

The Influence of Temperature on the Efficiency of Grinding. L. E. Djingheuzian. (*Trans. Canad. Inst. Min. Met.*, 1954, **47**, 157–168: *Canad. Min. Met. Bull.*, 1954, **47**, Apr., 251–262). Grinding trials on some non-ferrous ores and quartz are reported which show the favourable effect of temperature on grinding efficiency.—A. G.

How and Why Solids Agglomerate. C. Ludwig. (*Chem. Eng.*, 1954, **61**, Jan., 156–160). The uses of agglomeration processes are listed and factors governing its success are discussed. The importance of a size distribution with sufficient fines to give low voidage is stressed. Plasticity is achieved by an adequate size analysis and the addition of liquid plasticizers. The technique is illustrated by the extrusion of iron ore in a de-airing auger type agglomerator.

Evaluation of Sinter Testing. E. H. Kinelski, H. A. Morrissey and R. E. Powers. (*Min. Eng.*, 1954, **6**, May, 527–533). Twenty sinters or similar materials were used for an assessment of nine chemical and physical testing methods. The impact test results and the dust index were related to total porosity, which is explained in terms of a slag ratio and total slag content. With acid slag and high slag content, strong sinter was produced. Reducibility is influenced by the degree of oxidation, and is best assessed by chemical determination of FeO. (15 references.).—K. E. J.

Some Aspects on Sintering Operation and Sinter Usage. D. Joyce. (*Blast Furn. Steel Plant*, 1954, **42**, May, 515–520, 554; June, 657–664). The preparation of sinter for use in blast-furnaces is discussed in detail, particular reference being made to British and Swedish experiences. Results

obtained during the operation of blast-furnaces on sinter burdens are considered. Details of the practice adopted at the Algoma Steel Corp., which sinters a siderite ore, are described. Details of the blast-furnace and sinter plant operation are given. The effect of increase in the percentage of sinter in the burden is to decrease the coke rate and increase the iron make per day.—B. G. B.

Quality of Iron Ore Sinter as Related to Moisture and Coke Content. H. A. Morrissey and R. E. Powers. (*J. Met.*, 1954, **6**, Apr., 447–449). The authors have studied the effects of variations in moisture (10–16%) and coke (4–10%) on sintering conditions and sinter properties. The results are discussed and are shown to discount the possibility of producing a strong, dense, readily reducible sinter by varying only the moisture and coke in the sinter mix.—G. F.

Preparation of Ores: I. Methods of Improvement of Blast Furnace Burdens; II. The Sintering of Iron Ores; III. Theory of Sintering and Testing of Materials; IV. Other Methods of Agglomerating Fines and Direct Smelting Processes. J. M. McLeod. (*Iron Steel*, 1954, **27**, Feb., 49–54; Mar., 103–109; Apr., 145–151; May, 185–191). In Part I on ore preparation, the author deals with the development of methods during the last 80 years for improving the blast-furnace burden, dealing mainly with crushing and concentration. Part II is concerned with the sintering method of agglomeration, attention being given to the types of plant used for different ores, grading and mixing of the charge, and the sintering of five concentrates. The importance of uniform charging is stressed, and sinter cooling practice is considered. Part III then deals with the theory of the sintering process, including the effect of lime additions and sulphur removal in sintering. A discussion of methods of testing sinter follows, the properties dealt with being resistance to breakage, size, porosity, and reducibility. Other methods of fines agglomeration, namely pelletizing, briquetting, vacuum extrusion, and nodulizing, are considered in Part IV, followed by a discussion of direct smelting processes, including the manufacture of sponge iron and the Krupp-Rann process used with low-grade siliceous ores. (220 references).—G. F.

Taconite Beneficiation Comes of Age at Reserve's Babbitt Plant. O. Lee. (*Min. Eng.*, 1954, **6**, May, 484–488). At the Babbitt plant of Reserve Mining Co., ore of 18–28% iron content is concentrated and sent out as blast-furnace feed containing approx. 64·5% iron. The crushed ore is treated by magnetic separation, spiral classifiers, and hydroseparators to give a substantially − 325 mesh Fe_3O_4 product. This is pelletized in a drum and fired in a shaft furnace to give Fe_2O_3 pellets up to 1 in. in dia., with 30–32% porosity. Daily production is 100 tons.—K. E. J.

Upgrading Manganese Ore. S. J. McCarroll. (*Min. Eng.*, 1954, **6**, Mar., 289–293). Details are given of the flotation and nodulizing processes at Three Kids Mine, Nevada, which recommenced operations in 1952. Ore of 18% Mn content is upgraded to 46% Mn or better.—K. E. J.

Modern Plant Will Treat Mesabi Lean Ores. E. C. Herkenhoff. (*Eng. Min. J.*, 1954, **155**, Mar., 78–83). Details are given of the most modern of the plants to beneficiate lean Mesabi ores, at West Hill Mine of Pickands, Mather & Co. It commenced operations in July 1953, and treats 1000 tons/hr. The plant is divided into the pit screening and crushing section, the washing section, the heavy-media section, and the cyclone concentrator section (to be completed in 1954).

Sinter and Its Significance. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1954, **29**, Apr., 7–10). The production of sinter and the advantages of its use in iron making are briefly discussed.—V. G.

New Mineral Dressing Laboratories. (*Mine Quarry Eng.*, 1954, **20**, May, 225–230). A brief description is given of the reorganized mineral dressing laboratories at the Royal School of Mines.—D. L. C. P.

FUEL—PREPARATION, PROPERTIES, AND USES

Frontiers in Heat Extraction from the Combustion Gases of Coal. E. R. Kaiser. (*Min. Eng.*, 1954, **6**, Mar., 304–313). An account is given of recent work by Bituminous Coal Research, Inc. and other workers on increasing the efficiency of steam generating plant. Objectives for further work are improved control of ash and sulphur, and the cooling of flue gases to 150° F. (42 references).—K. E. J.

Energy Transfer in Hot Gases. (*National Bureau of Standards Circular* 523, Mar. 10, 1954). The National Bureau of Standards arranged 12 symposia in 1951 to mark the fiftieth anniversary of its establishment. The sixth of these, held on Sept. 17 and 18, 1951, was on Energy Transfer in Hot Gases and the proceedings are recorded in the present 126-page book. The papers presented were:

Processes of Electronic Excitation in Relation to Flame Spectra. A. G. Gaydon. (1–8).

Studies of Some Polyatomic Flame Bands. G. A. Hornbeck and R. C. Herman. (9–18).

Emission Spectra of Polyatomic Free Radicals. P. J. Dyne. (19–22).

Distributions of OH Rotational Intensities in Flames. H. P. Broida. (23–34).

Spectroscopic Studies of Low-Pressure Combustion Flames. S. S. Penner, M. Gilbert, and D. Weber. (35–37).

Studies of Emission and Absorption in Flames. G. H. Dieke and H. M. Crosswhite. (39–49).

Energy Distribution of CO Molecules in CO–O_2 Flames. S. Silverman. (51–56).

High-Resolution Spectra of Hydrocarbon Flames in the Infrared. W. S. Benedict and E. K. Plyler. (57–73).

Infrared Emissivity of Diatomic Gases. S. S. Penner. (75–85).

Infrared Spectra of Thermally Excited Gases. R. H. Turin. (87–91).

Present Position of the Theory of Flames. B. Lewis. (93–97).

Detailed Mechanism of Elementary Reactions: Production of OH($^2\Sigma^+$) in the H_2–O_2 Flame. K. E. Schuler. (98).

Some Reactions of Atomic Hydrogen in Flames. J. R. Arthur and D. T. A. Townend. (99–110).

Temperature of the Hydrogen-Fluorine Flame. R. H. Wilson, jun., J. B. Conway, A. Engelbrecht, and A. V. Grosse. (111–118).

Effect of Flame-Generated Turbulence on Heat Transfer from Combustion Gases. B. Karlovitz. (119–121).

Astrophysicist's Concept of Temperature. H. K. Sen. (123–126).

Thermal Lags in Flowing Systems Containing Heat Capacitors. J. W. Rizika. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Apr., 411–420).

Calculation of Transient Temperatures in Pipes and Heat Exchangers by Numerical Methods. G. M. Dusinberre. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, Apr., 421–426).

International Flame Radiation Research Committee—New Laboratory. O. A. Saunders. (*Nature*, 1954, **173**, June 19, 1160–1162). One furnace for oil and gas fuels is in operation and a second for pulverized coal is envisaged. All input variables are under automatic control and when the air preheater has been installed air can be supplied at any temperature up to 750° C. Further details of the furnaces are given together with a description of the experimental facilities, including electronic recorders and gas analysis recorders. Both performance and combustion mechanism trials will be carried out.—A. G.

A Theory of the Extinction of Diffusion Flames. D. B. Spalding. (*Fuel*, 1954, **33**, July, 255–273). A detailed investigation into the extinction of diffusion flames is made and a relationship has been derived which enables the velocity of a gas stream at which a flame surrounding a liquid sphere of fuel is blown out to be calculated.—B. G. B.

Comparison of the Spectra of Turbulent and Laminar Flames. A. G. Gaydon and H. G. Wolfhard. (*Fuel*, 1954, **33**, July, 286–290). Most laboratory work on flame spectra has been carried out on laminar flames although many industrial flames are maintained under conditions of high turbulence. Comparison of the spectra of laminar and turbulent flames has been made and no great differences have been found.—B. G. B.

Importance of Flame Configuration in Stability Experiments. P. F. Kurz. (*Fuel*, 1954, **33**, July, 291–294). Flame stability experiments with slow-burning and fast-burning fuels, and with binary fuel mixtures, on vortex burners showed that the flames of these combustibles must be similar in configuration in order to eliminate the influence of the burner and thus obtain results which will bear the proper interrelationships with each other.—B. G. B.

Lines of Development in Heat and Power Supplies in Iron and Steel Works. E. Krebs. (*Stahl u. Eisen*, 1954, **74**, June 17, 813–822). The heat and power consumption in integrated steelworks and the methods by which these may be reduced are discussed. These include the reduction of coke consumption in the blast-furnace, increased use of blast-furnace gas for metallurgical purposes and for coke-oven heating so as to save coke-oven gas for firing open-hearth furnaces, the efficient use of waste-heat boilers for generating steam and electricity, and the integration of power supplies with associated mining and chemical industries and local electricity authorities.—J. P.

Chemical Structure and Properties of Coal. IV—Pore Structure. P. Zwietering and D. W. van Krevelen. (*Fuel*, 1954, **33**, July, 331–337). The pore structure of coal was investigated by means of gas adsorption at room temperature, density measurements in helium at low temperatures, and determination of the penetration of mercury at high pressures.—B. G. B.

Chemical Structure and Properties of Coal. V—Aromaticity and Volatile Matter. D. W. van Krevelen and H. A. G. Chermin. (*Fuel*, 1954, **33**, July, 338–347). A graphical-statistical method is developed which enables the aromatic carbon fraction of coal to be determined when the value of specific gravity at 20° C. and the elementary analysis are known. As a first approximation, the aromatic fraction may be calculated from the content of volatile matter.—B. G. B.

Chemical Structure and Properties of Coal. VI—Calorific Value. J. Schuyer and D. W. van Krevelen. (*Fuel*, 1954, **33**, July, 348–354). An equation is derived by means of which, in principle, the calorific value of a coal can be calculated from data on its chemical composition and structure.

Power from Peat. (*Research*, 1954, **7**, Mar., 85–88). This is a critical review of the "Report of the Scottish Peat Committee." The deposits comprise 10^9 tons of solid matter (equivalent to 5×10^8 tons of coal), and their clearance would release 500,000 acres of land. Successful development depends on cheap means of winning and using peat; present work is largely concerned with methods of dewatering and burning in gas turbines, and the possibilities of "wet combustion". The recovery of useful chemicals appears to be doubtful, but a peat coke, possibly useful for metallurgical processes, can be made.—K. E. J.

Chairman's Inaugural Address. T. Abram. (*Yearbook Coke Oven Man. Assoc.*, 1954, 126–131). In his address on being elected chairman of the Northern Section of the Association, the author describes the reduction in ash and moisture content of coals carbonized at Fishburn since nationalization. The increase in production resulting from the installation of a centrifugal coal dryer is discussed along with the advantages and disadvantages of the addition of a froth flotation unit to the plant. The method of coal stocking adopted is described.—J. E. J.

The Oiling of Coal. H. Horsley. (*Yearbook Coke Oven Man. Assoc.*, 1954, 240–246). An account is given of the process adopted at Stanton to improve the uniformity of coke produced and to increase production. The bulk density of moist coal is increased and controlled by the addition of a small amount of oil. Tests carried out to establish the relationship between oil addition and bulk density are described. The oiling of coal provides a simple method of controlling flexibility of output.—J. E. J.

Effects of Oxidation of Coals on Their Flotation Properties. S. C. Sun. (*Min. Eng.*, 1954, **6**, Apr., 396–401). In view of the oxidation of coals during storage and the importance of recovery of coal fines from rivers, a series of tests was made on eight types of coal or carbon. Floatabilities generally decrease with increase in oxidation, when neutral oils are used, as a result of the formation of water-insoluble products. Certain cationic reagents are effective in the flotation of oxidized coals and cokes, and decrease of *p*H usually increases floatability. (22 references).—K. E. J.

The First Coal-Washing Plant in India at West Bokaro. D. M. Smith and H. G. Hague. (*G.E.C. J.*, 1954, **21**, Apr., 79–90).

The Physics of Electrostatic Precipitation. H. J. Lowe and D. H. Lucas. (Symposium on Static Electrification, Mar. 25–27, 1953: *Brit. J. App. Phys. Supplement No.* 2, s40–s47). Existing theories of the behaviour of particles in an electric field are summarized with special reference to the electrostatic precipitation of flue dust in power stations burning pulverized coal. The theoretical relation between particle size and precipitation efficiency is not borne out in practice, and consideration of the molecular and electrical forces acting in particles after deposition at the electrodes enables a modified precipitation cycle to be suggested.

Reduction of the Caking, Swelling and Smoke-Producing Properties of Coal by Chemical Pre-Treatment. A. H. Billington. (*Fuel*, 1954, **33**, July, 295–301). A great reduction in these properties of coal can be obtained by pre-treatment with nitrous oxide, nitric oxide, or nitrogen dioxide at temperatures below the decomposition temperature of the coal. Some possible applications of the method are considered.

A New Apparatus for the Determination of the Softening Behaviour of Coal on Coking. H. Echterhoff. (*Glückauf*, 1954, **90**, May 8, 510–516). After discussing the disadvantages of existing apparatus for determining the softening qualities of coal, the author describes an instrument based on Brabender's "Plastograph" modified to give results at temperatures up to 600° C., the temperature being controlled to $\pm$ 1–2° C. Results obtained with the instrument are given, and show good reproducibility.—L. D. H.

Coal Blending and Grinding for Carbonizing Purposes. J. E. Littlechild. (*Yearbook Coke Oven Man. Assoc.*, 1954, 263–287). A scientific approach to the problems of grinding and blending of coals formerly considered unsuitable for coking can result in the production of high quality cokes. Six types of coal blending are described and discussed together with the results of trials of various methods. An account is given of the problems of mixing, and types of mixers and their respective functions are described. Grinding before blending and the machinery for crushing and grinding are treated in detail.

Coke for Blast Furnaces. C. Hulme. (*Yearbook Coke Oven Man. Assoc.*, 1954, 145–153). The size and physical characteristics of coke are discussed in relation to gas passage and chemical reactions in the blast-furnace. Suggestions are made regarding means of reducing the liability to size reduction during handling, and an improved shatter test is described. Size segregation at the stock line and the possibility of reducing this effect by closer size grading are discussed.—J. E. J.

Coke Ovens and the Alkali Inspector. E. A. J. Mahler. (*Yearbook Coke Oven Man. Assoc.*, 1954, 227–239). The scope, requirements, and flexibility of the Alkali Act are discussed with particular reference to ammonia processes, benzene processes, acid sludge works, tar works, sulphur recovery processes, and processes which, although not registrable under the Alkali Act, may give rise to offensive emissions.—J. E. J.

Composition of Coal Tars. D. McNeil and G. A. Vaughan. (*Inst. Gas Eng., Publication No.* 438, Autumn Research Meeting, Nov. 24–25, 1953).

Tarmacadam and Tar Surface Dressing. J. M. Leech. (*Yearbook Coke Oven Man. Assoc.*, 1954, 338–346). A brief description is given of the various types and uses of tarmacadam covered by British Standard Specifications.

The Starting Up of a New Coke Oven Battery. R. C. E. Trewhitt. (*Yearbook Coke Oven Man. Assoc.*, 1954, 375–379). The question of solid or gaseous fuel for the initial heating of a new battery is briefly reviewed and gas is recommended, where available. The points which should be checked before heating are listed. The three stages of heating are defined, the total heating period being from six to eight weeks.—J. E. J.

The Nature of the Volatile Matter in Coke. T. Bispham and F. R. Weston. (*J. Inst. Fuel*, 1954, **27**, Apr., 201–208). Experiments are described which led to the conclusion that the volatile matter figures for cokes consist of two components, one being the residual gas left on completion of the carbonization proper, and one depending on the subsequent history of the coke. It is recommended that when a volatile matter determination is necessary to assess the degree of completion of coking, a 24-hr. test will give the best basis.

TEMPERATURE MEASUREMENT AND CONTROL

Optical Pyrometers, Their Functioning and Maintenance. H. E. Trent, jun. (*Steel Processing*, 1954, **40**, Apr., 237–241, 254). The design, construction, and operating principle of the disappearing filament potentiometric type optical pyrometer are described. Rules for effective maintenance are outlined, and methods of calibration are dealt with.

Use of a Thermal Model to Determine Temperature under Blast-Furnace Hearths. E. J. Williams and E. J. Burton. (*J. Iron Steel Inst.*, 1955, **179,** Jan., 17–22). [This issue].

The Measurement of Temperature Distribution in Heat-Treatment Furnaces. J. Nesnídal. (*Slévárenství*, 1954, **2**, (4), 100–102). [In Czech]. The temperature distribution in gas-fired annealing furnaces for iron and steel castings was determined by distributing a large number of hardened steel cylinders (1·2 in. in dia. × 0·7 in. long) on a skeleton framework in the furnace. The temperature–hardness relationship of the steel cylinders being known, it was possible, by remeasuring the hardness after the test, to determine the temperature to which each cylinder had been raised. From the hardness data isotherms were plotted which showed the temperature zones in the 600–920° C. range.

REFRACTORY MATERIALS

New Windham Works of Harbison-Walker Refractories Company. (*Refract. J.*, 1954, **30,** Apr., 147–151). An account is given of the manufacture of conventional and super-duty silica bricks at this highly mechanized plant.

High Temperature Insulation: Properties and Potentialities. G. E. Marsh. (*Sheffield Metallurgical Assoc.: Iron Steel*, 1954, **27,** May, 165–168; *Refract. J.*, 1954, **30,** Apr., 139–146). The author discusses the use of hot-face insulation in industry and indicates the potential economies in time and fuel, particularly in intermittent-working furnaces. The desirable properties of hot-face insulating bricks are listed and their limitations are outlined.—G. F.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Swedish Manufacture of Iron and Ingot Steel. S. Fornander. (*Jernkontorets Ann.*, 1954, **138,** (6), 311–332). [In Swedish]. After an historical review and a survey of the present raw materials situation, a description is given of the different processes used in Sweden for manufacturing pig iron, sponge iron, and ingot steel. A comparison is made between characteristic features of Swedish technology as compared with foreign practice, the differences being governed mainly by the scarcity of fossil fuels and adequate hydroelectric facilities.—G. G. K.

Some Notes on the Evaluation of an Iron Ore for Utilization in a Blast-Furnace. R. Kingston. (*Iron Coal Trades Rev.*, 1954, **168,** May 21, 1193–1199). The assessment of the value of an iron ore for the blast-furnace is based on a number of technical factors, including the content and chemical form of the iron, the chemical nature of the gangue, the sulphur and phosphorus contents, and the physical condition of the ore. The author discusses these factors in detail and describes their influence on blast-furnace practice.—G. F.

The Mechanism of the Reduction of Iron Oxides by Solid Coke. B. G. Baldwin. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 30–36). [This issue].

The Selective Reduction of Iron in Ilmenite and the Oxygen Pressure of TiO_{2-x} (Rutile). G. G. Michaud and L. M. Pidgeon. (*Trans. Canad. Min. Met.*, 1954, **47,** 187–189; *Canad. Min. Met. Bull.*, 1954, May, 187–189).

Construction of the Largest Blast-Furnace in Europe Completed in Record Time. D. R. Knall. (*Blast Furn. Steel Plant*, 1954, **42,** May, 524–530). Details are given of the design, construction and operation of a new furnace with a 28-ft. hearth at Westfalenhütte in Germany. The furnace has a carbon hearth, 20 tuyeres (each fitted with flow meter), and an automatic gas analyser, installed midway up the stack, which enable the CO_2, CO and hydrogen contents of the gas and the pressure and temperature to be measured across the burden.—B. G. B.

The Low Shaft Furnace. (*Echo Mines*, 1954, Mar., 168–170; Apr., 237–241; May, 312–314). The construction of the low-shaft furnace at Liège sponsored by O.E.E.C. is described in detail. Diagrams and photographs of this plant are given. The operation of a low-shaft furnace at Oberhausen is also discussed. This furnace is used to produce ferro-manganese and data are given for the furnace operating with and without oxygen-enriched blast. An increase in the reduction rate of 36·6% was obtained when a blast containing 30% oxygen was used. Brief mention is made of a low-shaft furnace at Köln-Kalk (Germany).—B. G. B.

Chemical Reactions of Coke in the Iron Blast Furnace. J. F. Peters. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200;** *J. Met.*, 1954, **6,** Apr., 466–474). In considering the reactions of coke in the blast-furnace the author first discusses the solution loss of coke and its effects on the efficiency of the process. Examples are given indicating that the reaction $CO_2 + C \longrightarrow 2CO$ is beneficial whilst the reaction $FeO + C \longrightarrow Fe + CO$ is detrimental. A theory is advanced explaining the contradictions encountered during earlier studies of the problem.—G. F.

TREATMENT AND USE OF SLAG

Utilization of Blast-Furnace Slag in the United States of America. P. Hüttemann and R. Mintrop. (*Stahl u. Eisen*, 1954, **74,** June 3, 778–781). The development of the use of blast-furnace slag in the U.S.A. is briefly described. The methods now in use for producing lump slag, foamed and granulated slag, and slag wool are discussed. Of the slag produced per year, 75% is utilized and of this amount, 80% is employed in lump form for road metal, airport runways, concrete aggregate, and railway permanent way ballast.

The State of Combination and Behaviour of Sulphur in Blast-Furnace Slag and Slag Wool. H. E. Schwiete and L. Zagar. (*Arch. Eisenhüttenwesen*, 1954, **25,** May–June, 195–206). X-ray fluorescence measurements have shown that the sulphur in blast-furnace slag wool is present as sulphide and to a small extent as sulphate. The sulphide is mainly calcium sulphide and is uniformly distributed within the fibres, whereas the sulphate is concentrated in the surface layers, presumably as a result of oxidation. Water extracts small quantities of cations and sulphur from the fibres, the amounts depending on the *p*H of the water. With water of normal *p*H, the extraction process ceases after 24 hr. The amount of sulphur leached out is about 2% of the total sulphur. It consists of sulphide and sulphate, predominantly the latter. Electrochemical tests in aqueous extracts from slag wool show that sulphide-bearing solutions lower the potential of steel, *i.e.*, they do not accelerate but inhibit corrosion.—J. P.

Properties and Applications of Iron Blast-Furnace Slag. J. R. Wallace, P. Fedora, and N. D. Weiner. (*Trans. Canad. Inst. Min. Met.*, 1954, **47,** 160–167): *Canad. Min. Met. Bull.*, 1954, **47,** Mar., 160–169). The characteristics and uses of blast-furnace slag are reviewed with particular reference to slags made by the Sydney plant of the Dominion Steel and Coal Company. Recently developed outlets include lightweight concrete and the use of slag as an acid neutralizer and soil conditioner in agriculture.—A. G.

PRODUCTION OF STEEL

Manganese-Free and Semi-Manganese Irons—Technical and Economic Comparison of Their Use in the Basic-Bessemer Converter. Rajon and Tavard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (3), 549–560). An examination has been made of the steel analyses, consumption of ferro-manganese, lime, scrap, and sodium carbonate, and the life of bottoms and linings to determine the effect of increased manganese in the iron. Steel quality improved with a saving of 245 francs/ton. From the blast-furnace aspect, the additional cost of manganese ore, when partially offset by gains on open-hearth slag, and savings in sodium carbonate, etc., amounted to 172 francs/ton of iron.—A. G.

Results Obtained at Moyeuvre, Using the Volume Rate Meter, in the Application of Conclusions Drawn from Tests on Scale Models at Grenoble. Leroy and Combert. (*Centre. Doc. Sid., Circ. Inform. Tech.*, 1953, (3), 521–542). After a brief outline of the major conclusions drawn from a study by the volume rate meter of factors influencing the blowability of a Bessemer charge, the application of these results at the Moyeuvre steelworks is described. Converters having a cylindrical internal profile and operating with a low bath height have been constructed. The advantages realised in this way include a gain in blowing time, longer bottom life, and a significantly lower nitrogen in the steel produced. A discussion of these results with some prepared contributions is included.—A. G.

Improvements in the Life of Bottoms and Linings (of Converters) by the Use of a Special Tar. Rajon. (*Centre Doc.*

Sid., Circ. Inform. Tech., 1954, (3), 542–544). Bottom joints made with this tar (described in an earlier paper) have a smooth crack-free surface but are easily broken out when necessary thus saving repair time. Results for lining life are now 11·5% better than in 1952.—A. G.

Oxygen Steels. Their Industrial Manufacture and Their Field of Application. J. Wurth. (*Rev. Tech. Luxembourg*, 1954, April–June, 78–79). A short account of the use of oxygen in the manufacture of steel by the basic-Bessemer process and the improved quality of such steels is presented.

Development of Oxygen-Blown Steel (LD Process). H. P. Weitzer. (*One Year LD-Oxygen Refining Process*: Vöest, Linz-Donau, 1954, 7–9). [In English]. The factors influencing the development of the LD (Linz-Düsenverfahren) steelmaking process are outlined. These included the need to economize in scrap which is needed for electric furnace alloy steel; the use of basic-Bessemer practice was precluded due to the unsuitable composition of the iron available, and the need for a low nitrogen product. Points in favour of the process are the low installation and labour costs compared with the same open-hearth tonnage, the high degree of metallurgical control, and the low consumption of refractories.—L. D. H.

The Metallurgical Principles of Steel Refining with Pure Oxygen by the LD Process. H. A. Trenkler. (*One Year Oxygen Refining Process:* Vöest, Linz-Donau, 1954, 11–15). [In English]. In the LD process, top blowing is employed using 98% oxygen supplied through a water-cooled nozzle. The converter is lined with dolomite magnesite, and the iron is high in manganese, with a phosphorus content of up to 0·25%. Due to the reactive slag formed at an early stage at a high temperature, phosphorus is removed during the foreblow; there is no afterblow, thus preventing over-oxidation. Nitrogen is low, averaging 0·004%. The heat balance compares favourably with basic-Bessemer practice; if required large amounts of scrap may be used. Slag condition, and the problem of smoke formation are discussed.

Planning and Erection of the LD-Steel Works. H. Schaden. (*One Year Oxygen Refining Process:* Vöest, Linz-Donau, 1954, 36–46). [In English]. Details are given of the layout and construction of the LD steelmaking plant and the associated oxygen plant.—L. D. H.

Operation Results within One Year. F. Klepp and R. Rinesch. (*One Year Oxygen Refining Process:* Vöest, Linz-Donau, 1954, 48–53). [In English]. Operation details of the LD process are given. Two 30-ton converters are used, lined with a hot face of tarred dolomite brick, backed with rammed tarred dolomite, and with a permanent lining of magnesite brick. A lining lasts in continuous operation for 7–8 days, with an average of 215 heats. A 1000-ton mixer is used charged with stahleisen previously desulphurized by treatment with soda. A typical charge-to-tap time was 32·5 min., with a blowing time of 18·3 min. Details of chemical charges during the blow are given.—L. D. H.

Basic Open-Hearth Practice at Volta Redonda. L. Cook. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 1–17). [This issue].

Starting and Operating Experiences at Abbey Melting Shop. A. J. Kesterton. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 46–57). [This issue].

On the Equilibrium Reaction among Aluminium, Oxygen, and Carbon in Molten Iron. T. Yagihashi and Z. Shibata. (*Sci. Rep. Res. Inst. Tohoku Univ.*, Series A, 1954, **6**, (1), 50–66). [In English]. An indirect measurement of deoxidation by aluminium was performed by using a pure carbon crucible in a carbon monoxide atmosphere in the range 1650°–2060° C. From the equilibrium constant of this reaction and that for CO gas, oxygen, and carbon in molten iron, the aluminium deoxidation equation was obtained. It was intermediate between the values of Geller and Dicke and of Wentrup and Hieber, and in good accord with open-hearth data. From a consideration of the system Al–C–O in molten iron, it was concluded that the deoxidizing power of aluminium is less than commonly supposed and that the molten metal must be deoxidized at a low temperature to get best results.—J. C. W.

The Thermodynamics of Carbon Dissolved in Iron Alloys. I—The Solubility of Carbon in Iron–Phosphorus, Iron–Silicon, and Iron–Manganese Melts. E. T. Turkdogan and L. E. Leake. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 39–43). [This issue].

The Thermodynamics of Carbon Dissolved in Iron Alloys. II—The Influence of Silicon and Phosphorus on the Activity Coefficient of Carbon Dissolved in Molten Iron. E. T. Turkdogan. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 43–45). [This issue].

Electric Furnace Operation: Trends in Modern Design. F. S. Leigh. (*Iron Steel*, 1954, **27**, Apr., 133–138; May, 169–174). The author deals with various electrical and mechanical features of an electric arc furnace which are of major importance in the design of an efficient and trouble-free unit. On the electrical side, attention is mainly given to the switchgear, transformer units, and automatic electrode control. The features of furnace design considered include the top-charging equipment, rotating shell, shell height, and the furnace lining. The use of Söderberg electrodes and magnetic stirring devices is also mentioned. Typical operating results are quoted and examples are given illustrating the wide range of uses of the arc furnace.—G. F.

Electricity and Steel. R. L. Gaunt. (*Elect. Rev.*, 1954, **154**, May 14, 875–878). The author discusses economic implications of the Batelle (U.S.A.) report in the use of electric furnaces in the manufacture of mild steel, referring to the type of furnace equipment available in Great Britain. The Batelle report concludes that mild steel can be produced more economically in arc furnaces than in open-hearth furnaces. It is pointed out that British types of furnace may have to be re-designed to suit quantity production. Better metallurgical control, good quality of the product, and the more favourable contrast in the present-day cost of electricity compared with the high increase in the price of other fuels may be deciding factors.—L. D. H.

Tool Steel : Shop Metallurgical Control by a Small User. J. A. Blackwell. (*Iron Steel*, 1954, **27**, June, 217–222). The author describes the steps taken in the establishment of technical control to ensure that makers of drills and similar tools receive steels of suitable quality and in the best possible condition for the particular application. The type of quality control described is applicable to most hardened steels.—G. F.

Fundamental Principles of Continuous Casting. P. Houseau de Lehaie. (*Publication de l'Association des Ingénieurs de la Faculté Polytechnique de Mons*, 1953, (4), 1–4). The normal cooling of ingots is first considered and the principles of ingot cooling are applied to the continuous casting process. The rate of cooling of the molten metal limits the rate of production of a continuous casting plant, and this factor is considered in detail.—B. G. B.

Results Obtained in the Field of Continuous Casting of Steel. J. Gouzou. (*Publication de l'Association des Ingénieurs de la Faculté Polytechnique de Mons*, 1953, (4), 5–11; (5), 10–22). A comprehensive account of continuous casting of steel up to 1952 is presented. Details of the design and operation of a number of plants in the U.S.A., Germany, Canada, Great Britain and Austria are given. A number of recent patents on this subject are considered. The majority of methods use vertical casting methods to produce billets but a method in which casting is carried out horizontally (Jacquet process) and a method for continuous production of steel in sheet form are also described. Twenty diagrams of continuous casting plants are given (94 references).—B. G. B.

Steel for Radially Stressed Heavy Forgings. O. Krifka. (*Stahl. u. Eisen*, 1954, **74**, June 3, 760–768). Ingot defects that militate against production of heavy rotor forgings and their causes are discussed, and the results obtained from several carefully observed heats are given. The best methods for producing sound steel are described. These include the control of the steelmaking, careful deoxidation by the carbon in the melt, and narrowing the casting temperature range. The most suitable casting-pit practice, including heating of mould hot-tops, is indicated.—J. P.

Contribution to the Study of the Heterogeneity in Ingots for Forging. M. Nepper. (*Rev. Univ. Min.*, 1954, 9th series, **10**, Apr., 96–99). Two 20-ton carbon steel ingots were cut in half and the segregation observed. The two ingots were of different shape and the steel was made in an open-hearth furnace under improved conditions. The geometrical shape of the mould influenced the segregation; the relationship between length and diameter governing the segregation. The distribution of carbon, sulphur, manganese and phosphorus through the ingots is shown.—B. G. B.

FOUNDRY PRACTICE

Some Variables in Acid Cupola Melting. S. Carter and R. Carlson. (*Amer. Found. Soc. Preprint* 22, 1954). Data from 45 heats in a small experimental acid-lined cupola have been analysed and an attempt is made to correlate coke size and size distribution, coke quantity, air volume, and size, shape and type of steel scrap with sulphur absorption, carbon pick-up, oxidation loss, slag composition, melting rate, and tapping temperature. The conclusions reached are discussed in relation to cupola size and some results are given of the behaviour of production cupolas to illustrate the principles developed from the experimental work.—B. C. W.

Correlation of Air Furnace Bottom Temperature to Refractory and Operating Practice in a Cupola/Air-Furnace Duplex System. F. W. Jacobs and E. C. Ashley. (*Amer. Found. Soc. Preprint* 55, 1954). Factors affecting refractory bottom life in an oil-fired air furnace used for duplexing have been studied over ten furnace campaigns. Particular attention was paid to the maximum temperature recorded just below the service bottom, and it was found that the lower this temperature the longer the life of the bottom. Details are given of slag control experiments and it is concluded that proper slag treatment is a major factor in increasing bottom life. Leakage of cupola slag on to the metal bath was found to give a rapid attack on the lining.

Melting Iron in the Reverberatory Furnace. C. G. de Laval. (*Foundry*, 1954, **82**, Mar., 224–234). The fundamentals of reverberatory furnace design, operation, and melting practice are reviewed and discussed. The importance of the action at the furnace throat in giving satisfactory melting is stressed together with the necessity for rapid melting.—B. C. W.

Cupola Fly-Ash Suppression. R. M. Overstrud. (*Amer. Found. Soc. Preprint* 82, 1954). The installation of a water-curtain cupola dust collector system at the Minneapolis-Moline Co., Minneapolis, reduced the time spent on roof cleaning from 2000 hr./year to 160 hr./year, and completely removed the previously existing fire hazard. The general plant atmosphere and working conditions around the cupola have been much improved.—B. C. W.

The New Variety of Coke for Cupolas. A. J. Zuithoff. (*Metalen*, 1954, **9**, May 31, 170–171). [In Dutch]. This is an American product known as 'High-Carbon Coke' made at present in small quantities under licence by the Verkaufs-Vereinigung für Teererzeugnisse (VET). It is claimed to be very compact and not very reactive. Although expensive, costing two-and-a-half times more than ordinary coke, only half the quantity is required to provide much greater melting capacity, higher temperature in the melting zone with consequent higher metal temperature when tapping, and the possibility of using a greater proportion of scrap. Good casting and mechanical properties are claimed by the Americans when this type of coke is used.—F. R. H.

Experiences with the Use of a Spray Type Collector on a 72-in. Cupola. A. G. Tompkins. (*Amer. Found. Soc. Preprint* 83, 1954). An inexpensive spray-type dust collector is briefly described and data obtained on collector efficiency and air pollution are reported.—B. C. W.

Calcium Carbide Injection—A New Foundry Tool. H. E. Henderson and J. M. Crockett. (*Amer. Foundryman*, 1954, **25**, Apr., 34–43). Calcium carbide injected into molten iron by means of dry nitrogen removes sulphur and provides a satisfactory base iron for subsequent spheroidization. The construction and operation of an injection assembly is described and results obtained with both intermittent and continuous use are presented. The sulphur content of the iron may be readily reduced from 0·2 to <0·02% and this enables high strength irons to be obtained with more economical alloy additions. Calcium carbide injection as a preliminary to spheroidization has the advantages of reducing the amount of magnesium or cerium required, and, by producing less variation in the sulphur content, it gives better control of the final product. By injecting spheroidizing agents with the calcium carbide, irons of various tensile strengths can be obtained from the same base material.

Research on the Use of Magnesium-Ferrosilicon Alloys and Magnesium Alloy Scrap for the Production in a Cupola of Molten Nodular Iron. J. Piaskowski. (*Przeglad Odlewnictwa*, 1954, **4**, (5), 132–140). [In Polish]. Experimental trials in the production of nodular iron using magnesium-ferro-silicon alloys containing about 20% Mg, showed that the presence of copper and aluminium in these alloys has no appreciable influence on the properties of cast iron. Better results were obtained with alloys containing 10–12% Mg, but the use of an alloy of magnesium with calcium silicide for innoculation gave no improvement. Tests with magnesium alloy scrap as an innoculant showed that extra scrap must be added after the white fracture is obtained in the test. The main mechanical properties of nodular iron were examined and their improvement by a normalizing heat-treatment was observed.—V. G.

Nodular Cast Iron—Its Present Position and Future Prospects As an Engineering Material, with Special Reference to Its Suitability for Crankshafts. S. B. Bailey. (*Inst. Mech. Eng., Advance Copy*, 1954, Apr. 30). The economics of the production of nodular iron by various methods are discussed. It is concluded that material produced by the magnesium-nickel process cannot compete in price with established materials such as carbon steel and malleable iron. Methods for direct addition of magnesium to molten iron are described, and application of these methods to low-sulphur irons from basic cupolas may completely alter the situation. The engineering properties of nodular cast iron are compared with those of other ferrous materials, and its use as a replacement for high-grade flake-graphite and malleable irons and carbon steel is discussed in detail, particularly from the economic viewpoint. It seems doubtful whether the fatigue properties of nodular iron will permit of its replacing the forged low-alloy steel crankshafts in British engines unless some reduction in specific power output is accepted. (52 references).—P. M. C.

Some Effects of Melting Furnace Atmospheres on Tensile Properties and Annealability of Malleable Iron. G. E. Kempka and R. W. Heine. (*Amer. Found. Soc. Preprint* 50, 1954). The effects of the furnace atmosphere on the mechanical properties and graphitization of malleable iron were determined for neutral, reducing, oxidizing, and moist combustion gas mixtures. The atmosphere was maintained over the charge in an induction furnace during both the melting down and holding periods. High nitrogen mixtures gave high strength irons which, however, were more resistant to mottling and required longer graphitizing times. Water vapour had no effect on annealability but produced shrinkage cavities and poor tensile properties. Free oxygen in the furnace atmosphere not only caused high silicon losses but also gave an increased resistance to graphitization and lower tensile properties. Furnace atmospheres exert their greatest effect during melting down rather than during refining.—B. C. W.

Pouring Temperature Effect on Steel Castings. C. F. Christopher. (*Amer. Foundryman*, 1954, **25**, Apr., 51–55). The interrelation of carbon content, pouring temperature, amount and type of deoxidizer, porosity, and type of sulphide inclusion for steel castings is discussed. It is concluded that the lower the pouring temperature the less the porosity and the more efficient the deoxidisers. Curves are given for determining the maximum pouring temperature and for calculating the aluminium additions required to avoid both porosity and inclusions.—B. C. W.

Effect of Moisture Content on Silica Sand. E. D. Sayre and C. T. Marek. (*Amer. Found. Soc. Preprint* 2, 1954). The theories advanced to explain why there is a minimum in the bulk density of sand–water mixtures with increasing water content, are discussed and a new theory is put forward. Results obtained for bulk density, mould hardness, and compressive strength with four different sand grain sizes and moisture contents ranging from zero to inundation, are presented and discussed. With decreasing grain size the minimum bulk density falls and a greater maximum strength and hardness is developed.—B. C. W.

Heat Transfer of Various Molding Materials for Steel Castings. C. Locke and C. W. Briggs. (*Amer. Found. Soc. Preprint* 61, 1954). The heat extracting ability of 25 possible moulding materials was compared by measuring the time for the solidification of 6-in. cast steel spheres. Details are given of the development of mouldable mixes and the advantages and disadvantages of each material for moulding are summarized. Magnesite was the best and cheapest mouldable chill although zircon was much easier to mould. A 40/60 mixture of diatomaceous earth and sand with phenolic

resin as a binder was a very effective insulator, whilst a thermit–silica mixture was most effective in retarding solidification. Correction factors to be used in calculating the feeding distance of risers are given for 18 of the materials.

Selection and Mulling of Synthetic Sands. C. E. Wenninger. (*Amer. Found. Soc. Preprint* **34,** 1954). The selection and mulling of synthetic foundry sands are discussed in general terms from the point of view of the orderly packing of different sized sand grains. The effect of grain shape is briefly considered.—B. C. W.

Casting Quality as Related to pH Value of Moulding Sands. V. E. Zang and G. J. Grott (*Amer. Foundryman*, 1954, **25,** Mar., 49–59). Results are presented to show that casting quality may vary appreciably with the *p*H value of the moulding sand. The meaning of *p*H is briefly considered and the effect of chemical additions on the properties of clay illustrated by results showing the variation of the viscosity of clay slurries with *p*H. The application of *p*H control to practical sand control is discussed in detail.

Synthetic Resins. H. H. Shepherd. (*Australian Found. Trade J.*, 1952, **3,** June, 3–5, 7, 9, 11; July, 3–5, 7–9). Two types of synthetic resins, urea and phenol formaldehydes, have been successfully applied in recent years as foundry core binders. The properties and relative merits of both types are discussed, and practical details of their use are given. Some notes on dielectric (H.F.) core baking are included.—P. M. C.

Metal Penetration Tests on Dry Sand Cores and Core Washes. (*Amer. Found. Soc. Preprint* 69, 1954). Experiments carried out on the prevention of metal penetration into dry sand cores showed that a silica wash prevented penetration by grey iron but that a graphite wash gave uneven results, allowing penetration to occur at the corners of the specimen.

Risering of Nodular Iron. R. C. Shnay and S. L. Gertsman. (*Amer. Found. Soc. Preprint* 40, 1954). Experimental results obtained on the feeding of semi-circular plate castings in nodular graphite iron are reported. The plate thicknesses were, $\frac{1}{2}$, 1, and $1\frac{1}{2}$ in., and the feeding distances for various combinations of riser diameter and riser height were determined for each thickness. The maximum feeding distance was obtained with a riser diameter greater than $(2t + 1)$ in. where t is the plate thickness. The boundary condition for under-riser shrinkage was found to be given by Caine's equation

$$\frac{A_C\, V_R}{V_C\, A_R} = \frac{a}{V_R/V_C - b} + C$$

where A_C, V_C, A_R, and V_R are the surface area and volume of casting and riser respectively, although agreement was not good for castings with 6-in. risers.—B. C. W.

Recommended Names for Gates and Risers. (*Amer. Foundryman*, 1954, **25,** Apr., 63–65). This is a short glossary of terms, with many explanatory diagrams, prepared by the Gating and Risering Committee, Gray Iron Division of the American Foundrymen's Society.—R. A. R.

Methods for Special Pipe Production in Australia. G. J. Benson. (*Amer. Foundryman*, 1954, **25,** Mar., 63–67). A detailed description is given of the moulding practice used for a 48-in. internal dia. **T**-pipe and for a flanged 90° bend pipe 54 in. in diameter.—B. C. W.

Pressure Moulding with Standard Synthetic Sand. T. E. Barlow and W. R. Adams. (*Amer. Found. Soc. Preprint* 44, 1954). The theory of high pressure moulding is briefly discussed and results are presented of an investigation to determine the possibilities of pressure moulding with ordinary green sands. It was found that changing from jolt squeeze to high pressure squeeze (100 lb./sq. in.) did not make any major difference in casting appearance or dimensional stability. The application of pressure moulding to sand of high flowability is briefly considered.—B. C. W.

Core Blowing Problems. J. A. Mescher. (*Amer. Found. Soc. Preprint* 65, 1954). The principles of core-blowing are briefly considered and the problems of core quality, core-box maintenance, reducing set-up time, and high speed production are discussed. Different types of core-blowing machines are illustrated and described.—B. C. W.

Fluidity *vs.* Core Blows in Automotive Gray Iron. A. A. Evans. (*Amer. Foundryman*, 1954, **25,** Apr., 66–68). Using a new fluidity test, a correlation was found between fluidity and the percentage of gas cavities; with increasing fluidity the number of core blows decreased. The fluidity test, which is described and illustrated, is compared with previous tests. It is now being used as a quality control test in the production of cylinder blocks and heads.—B. C. W.

Job Simplification by MTM. I. Edman. (*Gjuteriet*, 1954, **44,** June, 95–101). [In Swedish]. The American 'methods time measurement' (MTM) procedure has been used in the author's foundry for systematic work simplification. Principles of the method are outlined, and an account is given of how it should be applied. Examples are given of MTM studies of machine moulding and of the trimming of large and small castings. Improvements introduced as a result are described.—G. G. K.

Recommendations for Drying Stoves. (*Gjuteriet*, 1954, **44,** June, 102–105). [In Swedish]. These suggestions, made by a Swedish foundry committee, are intended to improve stove design. They deal with: Thickness of thermal insulation of stove walls, thermal storage capacity, door design, gas circulation, combustion chambers in non-electric stoves, and control gear and equipment for electrically-heated units.—G. G. K.

Horizontal-Axis Centrifugal Casting. A. J. Gibbs Smith. (*Canad. Metals*, 1954, **17,** Apr., 28, 32). A description of a horizontal casting machine is given together with details of the practice used in the manufacture of cast-iron pipes. The advantages of the centrifugal method over conventional sand casting are explained.—B. G. B.

Casting of Surface-Hardened Plate. E. M. Blank. (*Liteĭnoe Proizvodstvo*, 1953, (2), 30–31). [In Russian]. In the procedure described, plates of a graphitized steel (1·0–1·2% C, 1·2–1·5 Si, 0·4–0·5% Mn, 0·2–0·3% P, 0·02–0·03% S) for ball mill drums are chilled by being cast in a mould covered with a cast-iron plate which has a life of about 500 moulds. [This supersedes the abstract "Casting of Armour Plate" on p. 466 of the August, 1954, issue of the *Journal*].

Some Experiences with Shell Moulding in the Magnet Steel Foundry. A. J. J. Koch. (*Metalen*, 1954, **9,** May 31, 157–162). [In Dutch]. The author briefly discusses the older methods of producing magnetic steels, referring to the Japanese Mishima variety and then describes in detail the composition and characteristics of "Triconal" (developed by Philips Laboratories) and the production of magnets therefrom using the shell moulding process. The quality of sand required and the moulding process are outlined.—F. R. H.

Research on Shell Moulding. R. G. Powell, C. M. Adams, jun., and H. F. Taylor. (*Amer. Found. Soc. Preprint* 45, 1954). The strength of tensile specimens prepared from sand–resin mixtures was determined to establish the factors which influence resin consumption in shell moulding. Among the aspects considered were the bonding efficiencies of various commercial phenolic resins and the effects of dwelling and curing conditions, resin particle size, sand grain size, cleanliness and shape of sand grains, mechanical packing of sand and resin, nature of the moulding sand and the surface treatment of silica sands. The strength of the shell moulds was considerably increased by vibration during the dwelling period and the use of either clean or coarse-grained sand decreased resin consumption. The mechanism of cohesion between sand and resin is considered and a theory of hydrogen bonding is suggested.—B. C. W.

Heat Transfer Characteristics of Metals Cast in Shell Moulds. R. E. Morey, H. F. Bishop, and W. S. Pellini. (*Amer. Foundryman*, 1954, **25,** Apr., 46–50). The solidification time of shell moulded castings is less than that of similar sand moulded castings by an amount that depends on the nature of the back-up material and the shell/casting thickness ratio. The maximum decrease is 30–40% obtained with shot back-up and 10% with gravel, both for a shell/cssting thickness ratio of about 0·1. Castings poured in open shells show an increase in solidification time as compared with sand moulds, the increase ranging from 40% with steel to 80% with aluminium castings.—B. C. W.

Investment Casting by the Frozen Mercury Process. I. R. Kramer. (*Amer. Found. Soc. Preprint* 52, 1954). In the frozen mercury process, a pattern is made by pouring liquid mercury into a steel die at room temperature and then freezing the mercury at −100° F. (−73° C.). The relatively low expansion of mercury on melting enables a thin ceramic shell mould ($\frac{1}{16}$ to $\frac{1}{8}$ in. thick) to be used, and this is built up by dipping the pattern into slurries of increasing viscosity at − 80° F. (− 62° C.). The mercury is then washed and melted out and the mould is ready for firing. The shell

mould enables suction casting to be used and permits ready removal of cores. The frozen mercury process can be used for larger and more complex shapes than other forms of investment casting.—B. C. W.

Studies of Chill Action. E. T. Myskowski, H. F. Bishop, and W. S. Pellini. (*Amer. Found. Soc. Preprint* 64, 1954). The influence of centre chills on the solidification of long steel bars was determined by thermal analysis, and the effects of chill thickness and sand spacing between chill and bar were investigated. Direct chills produced an instantaneous skin and gave a sharp transition in solidification rate at the edge of the chill which is considered to be responsible for hot tearing in this region. Indirect chills prevented the development of a sharp transition zone and have the further advantage of removing undesirable hot spots without blocking centre-line feeding channels.—B. C. W.

Solidification of Various Metals in Sand and Chill Molds. F. A. Brandt, H. F. Bishop, and W. S. Pellini. (*Amer. Found. Soc. Preprint* 62, 1954). The solidification characteristics of various ferrous and non-ferrous metals cast in chill and sand moulds were determined by thermal analysis. The metals studied included plain carbon steel, and 12% chromium and 18/8 stainless steels. The relative solidification times in both sand and chill moulds are discussed in terms of the mechanism of freezing.—B. C. W.

Solidification of Finite Cylinders. V. Paschkis. (*Amer. Found. Soc. Preprint* 31, 1954). Results are presented of calculations carried out to investigate the solidification of cylinders with length/diameter ratios above 2. The calculations ignore the mould but have been made allowing for changes in the surface temperature of the castings. Curves to show how the times to reach liquidus and solidus vary with the length/diameter ratio are given, and the solidification times for slabs are compared with those for short cylinders, *i.e.*, discs. The validity of Chevoinoff's theory of solidification times is discussed and the development of a simple equation relating the solidification time of cylinders to their shape, is considered.—B. C. W.

Importance of Cooling Rate on Physical Properties of Gray Cast Irons. J. Henry. (*Amer. Found. Soc. Preprint* 28, 1954). Previous work on the influence of cooling rate and section size on the properties of grey cast iron is briefly reviewed and results are presented to show the effect of the time between pouring and mould shake-out on the hardness and tensile strength of castings and test-bars. Cooling curves for different shake-out times are given and are correlated with the properties and microstructure. The results show that the hardness and tensile strength of grey cast irons are increased by shaking out the castings above the Ae temperature.—B. C. W.

Computation of the Rate of Solidification of an Ingot, Taking Into Account the Temperature Dependence of the Thermophysical Parameters of the Metal. B. Ya. Lubov. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **92,** (4), 763–766; *National Science Foundation Translation* 227, Feb., 1954). In order to compute more accurately the rate of advance of the crystallization front during solidification of a metal ingot a method of determining the dependence of thermal conductivity and heat capacity of a solid metal on the absolute temperature is presented.—V. G.

Ideal Foundry in Pictures. (*Organisation for European Economic Co-operation, Report of Technical Assistance Mission No.* 111, 1954). [In French and English]. This 64-page report, with its numerous illustrations, describes foundries in the U.S.A. visited by a European Mission. It emphasizes the attention paid in the U.S.A. to mechanization, lighting, ventilation, and working conditions.—R. A. R.

HEATING FURNACES AND SOAKING PITS

Rotary-Hearth Forging Furnaces. (*Metal Treatment and Drop Forg.*, 1954, **21,** May, 251, 250). The latest heating equipment at the Kilsta Drop Forge, Bofors, Sweden, is described. Five rotary-hearth billet heating furnaces were erected by Salem Engineering Co. Ltd. in 1952–53. Two of these have 14 ft. 5 in. dia. hearths and maximum outputs of 2 tons/hr. The other three have 18 ft. 4 in. hearths and hourly outputs of approximately 3½ tons. Details of the furnace construction and ancillary equipment are given.

Heat Indices of Heating Furnaces Used in the Steel Industry. J. Klimek and S. Podgornik. (*Hutnik*, 1954, **21,** (5): *Biuletyn Informacyjny Instytutow Ministerstwa Hutnictwa*, 1954, **5,** (5), 17–20). [In Polish]. The results of heat measurements on furnaces operating in a rolling mill and a forge are described. These measurements were carried out to determine heat losses and to study the possibilities of reducing them.—V. G.

Industrial H.F. Induction Heating. (*Machinist*, 1954, **98,** May 1, 721–728; June 5, 985–988). Economic saving through increased rate of production, ability to employ cheaper labour, or by the elimination of operations which would be necessary if other forms of heating were employed, are demonstrated by the application of H.F. power. These include the use of H.F. induction heating for melting cast iron, surface hardening of components and re-heating of steel billets. British made equipment is reviewed.—M. A. K.

Recovery of Waste Heat for Space Heating Purposes. F. Bleimann. (*Stahl u. Eisen*, 1954, **74,** June 3, 773–777). The planning, erection and operational results of a waste-heat recovery plant, attached to a rolling mill, for heating an office block and a workshop are reported. The saving of fuel as compared with the use of a coke-heated central installation paid for the waste-heat system in two years.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Accurate Furnace Control Required in Processing of High-Speed Steels. F. A. Locke. (*Indust. Heating*, 1954, **21,** May, 915–920). A brief review of hot working practice is given. Stress is laid on the avoidance of decarburization of molybdenum steels. Methods suggested for obviating it are scaling of the stock, use of protective coatings during heating (such as borax), and a carburizing atmosphere during annealing.

Ultra-Modern Heat Treating Facilities at New Plant of Metallurgical, Inc. (*Indust. Heating*, 1954, **21,** Apr., 680–690). A detailed description of the plant is given. Automatic control of furnace temperature, furnace atmosphere and plant operation is widely employed. An electric furnace taking 3-ton loads for bright annealing, normalizing and carburizing, two radiant-tube heated furnaces, a smaller electric furnace, and a Lindberg tempering furnace are housed in one large pit, and several different furnaces for treating various metals occupy a smaller pit. There is a large generator supplying a protective atmosphere called Neutralene.—R. A. R.

Continuous Reciprocating Furnaces. F. C. Schaefer. (*Metal Treating*, 1954, **5,** Jan.-Feb., 8, 9, 14). The design, operation, and applications of reciprocating heat-treatment furnaces are described. In such furnaces a forward motion is imparted to the hearth and the workpieces and it is then suddenly interrupted. The work slides forward by its own momentum until stopped by friction. By repeating this process at intervals, the work is advanced step-by-step through the furnace.—P. M. C.

Gear Teeth in Welded Segments Induction Hardened and Tempered. H. J. Boll. (*Metal Treating*, 1954, **5,** Mar.-Apr., 6, 7, 14). Equipment is described and illustrated which was designed specifically to harden and temper gear teeth in large welded segments, one tooth at a time. After induction heating and water quenching, each tooth is tempered individually by reheating to 900° F., using the same small coil. Furnace tempering of the whole component is impractical in this particular case owing to distortion caused by the high tempering temperature.—P. M. C.

More Life for Big Guns. W. C. Longstreth. (*Steel Processing*, 1953, **39,** Dec., 664–666). A very brief description is given of the furnaces and quench tanks used to heat-treat long gun barrels at the Midvale Company, Philadelphia. The vertical furnaces, 8 ft. in dia., have three separately controlled gas-fired zones. The water-quenching tanks are over 100 ft. deep and the circulating coolant is temperature controlled.—P. M. C.

Heat Treatment in Steam. Tempering, Annealing and Stress-Relieving of Metals in a Steam Atmosphere. B. R. Swann. (*Metal Treatment and Drop Forg.*, 1954, **21,** Apr., 168–172, 167). The benefits and limitations of heat-treating metals in an atmosphere of steam are discussed. Certain advantages are evident between 280 and 625° C. for ferrous materials, a thin blue film of oxide (Fe_3O_4) being formed. High-speed steel tools exhibit marked increase in life, due possibly to the lubricant retaining property of the porous

oxide film and the reduced tendency for welding of the cut chips. Increased resistance to corrosion is reported for steel other than high-speed, and sintered iron powder compacts show improved wear resistance, hardness, and corrosion resistance.—P. M. C.

New Surface Hardening Unit Provides Accurate Temperature Control. J. H. Bockrath. (*Metal Treating*, 1954, **5,** Jan.-Feb., 2, 3, 18). A new and extremely flexible surface hardening unit designed by the Weidemann Machine Co., Philadelphia, is described and illustrated. All types of gears, segments, and cylinders up to 36 in. in dia. and 12 in. face width can be accommodated by the unit, which incorporates 20 or more Selas Superheat gas burners in adjustable mountings. A feature of the equipment is a Leeds and Northrup Rayotube temperature sensing element coupled to a Speedomax recorder. A signal is given when the heated surface reaches a pre-arranged temperature.—P. M. C.

Heat-Treatment of Steels on the Basis of their Transformation Diagrams. F. Wever and A. Rose. (*Stahl u. Eisen*, 1954, **74,** June 3, 749–759). The application of isothermal and continuous time-temperature-transformation diagrams to the practical heat-treatment of steel and cast iron has been indicated by reference to a series of examples. Isothermal diagrams are of importance, particularly for isothermal annealing to pearlite and intermediate stages, and for hot-bath hardening. Continuous transformation diagrams have been used for indicating the cooling processes for the formation of pearlite and intermediate stage structures as well as for quench hardening. The connection between hardenability, hardenability coefficient, and through-hardening of various cross-sections are made obvious.—J. P.

Contribution to the Study of Certain Factors Involved in the Induction Hardening of Surfaces. G. Remy. (*Rev. Mét.*, 1954, **51,** Feb., 85–100). In the induction hardening of surfaces the rapid local heating produces special conditions of the austenite, which determine the hardenability of the steel. Investigation shows that these conditions depend on the power supplied, the duration of heating, and above all on the microstructure of the steel.—A. G.

High Pressure Nitriding for the Heat Treater. R. L. Chenault and G. E. Mohnkern. (Metal Treating Institute: *Metal Treating*, 1954, **5,** Mar.-Apr., 2–5, **36,** 37). A high-pressure method of nitriding small parts, using ammonia vapour, is described in detail. The parts are heated to 1000° F. in a container which is supplied with vapour at pressures up to 800 lb./sq. in. The ammonia may be supplied under pressure from a storage bottle, or introduced, before heating, into the pressure chamber in a small steel capsule. In the latter method the quantity of liquid ammonia is calculated to produce the desired pressure on subsequent vaporization. Experiments are reported on a 3% Hi–Cr–Al steel and an aluminium alloy which show improvements in hardness, case-depth, and structure over conventional nitriding processes. The effects of pressure variation, temperature, and time are discussed. The process is patented by the U.S. Steel Corp. and is designated " Nitrocycle."—P. M. C.

Electric Furnaces with Controlled Atmospheres. M. Chain. (*J. Four. Elect.*, 1953, **62,** Nov.-Dec., 169–176). The chemical principles of the CO/CO_2 and H_2/H_2O equilibria with iron and iron oxides are first considered and the practical methods used to obtain a controlled atmosphere are described. Examples are given of equipment for bright annealing and case-hardening.—B. G. B.

A Survey of Quenching Oils. J. McElgin. (*Steel Processing*, 1954, **40,** May, 315–318). The desirable characteristics of a quenching oil are enumerated, and the uses and properties of straight and compounded mineral oils and new types of high speed quench oils are discussed.—P. M. C.

FORGING, STAMPING, DRAWING, AND PRESSING

Precision Forging of Jet Engine Parts. J. L. Holley and D. P. Patterson. (*Indust. Heating*, 1954, **21,** May, 872–885, 1028–1030). Details are given of the plant and practice at the Studebaker Corp. for the manufacture of jet engine brackets and blades using alloy S816 (0·3–0·45% C, 18–22% each Ni and Cr, 3·5–5·0% Mo, 3·5–8·0% W, 2·5–4% Cb, 4% Fe, 38% min. Co). Induction heating, and automatic temperature and atmosphere control are widely employed.—R. W. B.

New Forging Manipulator: Wellman 5-ton Mobile Machine. (*Iron Steel*, 1954, **27,** June, 233–234). **Mobile Forging Manipulator.** (*Brit. Eng.*, 1954, **37,** July, 27–30: *Brit. Steelmaker*, 1954, **20,** June, 210–211). A new manipulator, built by the Wellman Smith Owen Engineering Corporation Ltd., will be used for charging and discharging reheating furnaces and subsequently handling ingots or billets under the forging hammer or press. It weighs 24 tons and its rated capacity is 5 tons. The separate motions embodied are grip, parallel hoist, rocking hoist, bar turning, travelling, and steering.—K. E. J.

Hydraulic Variable-Speed Rotary Drives in Industry, with Notes on Some Interesting Applications. F. B. Levetus. (*Inst. Mech. Eng., Conference on Hydraulic Mechanisms*, 1954, Mar. 26, 21–24). Various types of hydraulic drive with different characteristics are described. Of particular interest is the application of a controlled acceleration and deceleration type to a screw forging-press of 1000 tons capacity. The flywheel of the press is driven by two hydraulic motors operating in parallel at a maximum speed of 1400 r.p.m., each developing 70 h.p., the maximum pressure being of the order of 1050 lb./sq. in. Details are given of the hydraulic circuit necessary to accommodate high-speed reversal without undue shock.—P. M. C.

Some Problems in the Development of a 50,000-Ton Press. H. C. Hood. (*Steel Processing*, 1953, **39,** Dec., 642–646, 670). Details are given of the design and problems encountered in the construction and fabrication of the 50,000-ton Lowey hydraulic press now nearing completion in the U.S.A. The press, which will be used to forge large precision aircraft components at the Wyman-Gordon Co. plant, weighs 10,750 tons and is 110 ft. high, 66 ft. being below ground level.

The Hydroform As a Production Tool. L. F. Spencer. (*Steel Processing*, 1954, **40,** Apr., 243–248). The hydroform process, developed by the Cincinnati Milling Machine Co. for the press forming of sheet metal components, is described. Deformation is obtained by the action of a rubber diaphragm attached to the press ram, and a punch located in the bed of the press. The rubber diaphragm is activated by hydraulic fluid located in a cavity in the ram, and replaces the female die in conventional presswork. The blank is pressed into the flexible diaphragm by the forming punch. Several advantages of the process over ordinary press drawing, particularly the reduction in the number of operations, are discussed.

Springback in Metal-Forming : Variation with Conditions. F. Strasser. (*Iron Steel*, 1954, **27,** June, 235–236, 240). The author enumerates and discusses the factors determining the occurrence of ' springback ' in metal-forming operations. Four methods of overcoming springback, namely over-bending, re-striking, the use of special dies, and heating of the blanks, are briefly described.—G. F.

Metal Spinning, Its Implications and Applications. L. F. Spencer. (*Steel Processing*, 1953, **39,** Dec., 631–640). A general review is presented of the metal spinning process with special reference to the economics of the method in comparison with deep drawing. The author discusses design of spinnable shapes, equipment requirements, spinning speeds, and the relative spinnabilities of various non-ferrous and ferrous materials, including 18/8 stainless and plain carbon steels.—P. M. C.

Allegheny Ludlum Hot Extrudes Stainless, High Alloy Steels. E. C. Beaudet. (*Iron Age*, 1954, **173,** Mar. 25, 137–140). A high-speed double-acting press of 1778 tons capacity is used to produce tubing $1\frac{5}{8}$ to 4 in. in dia. at the rate of 25 to 30 pushes/hr. A variable accumulator system operating at 3150 lb./sq. in. is used for the high-pressure movements. Additional equipment includes salt-bath furnaces and a stretcher-straightener. Shapes are also being produced and titanium, zirconium, tool steels, and high-temperature alloys are being extruded experimentally.

Cold Extrusion of Steel. W. J. Meinel. (*Sheet Metal Ind.*, 1954, **31,** Mar., 198–202). A general account is given of the rapid advances and capabilities of the cold-extrusion process as applied to the production of shell bodies and other ammunition components. The article is based on experience gained by the Heintz Manufacturing Co. who pioneered this process in the U.S.A.—P.M.C.

An A.B.C. of Cold Extrusion of Steel. J. Perry. (*Trans. Canad. Inst. Min. Met.*, 1954, **47,** 64–67; *Canad. Min. Met. Bull.*, 1954, **47,** Mar., 132–135). By cold extrusion is meant a reduction in cross-section of up to 90% in one operation,

using a phosphate lubricant applied as an acid phosphate solution (generally zinc). The choice of steel, and type of press, the method of extrusion, and tool material and construction are discussed. The process results in an uneven flow pattern so that the interpretation of results on test pieces requires great care.—A. G.

Researches Concerning Wire Drawing Dies. J. G. Wistreich. (*Australian Inst. Met., Symposium on "The Theory and Practice of Wire Drawing,"* Nov. 13, 1953, *Preprint: Wire Prod.*, 1954, **3,** Mar., 7–10, Apr., 9–11). The following topics are surveyed: Conditions at the die-wire interface, die temperature, friction and lubrication, wear; die materials, their strength and profile; die performance, and the measurements of profiles. (55 references).—J. G. W.

Drawing Practice for Special Steel Wire. A. Wilczek. (*Draht, German ed.*, 1954, **5,** Apr., 120–123). Heat-treatment and drawing practice in the manufacture of wire from electric furnaces and alloy steels are described. The effect of cold work on the properties is noted.—J. G. W.

ROLLING-MILL PRACTICE

An Examination of Modern Theories of Rolling in the Light of Rolling Mill Practice. N. H. Polakowski. (*Sheet Metal Ind.*, 1950, **27,** May, 389–399, 402; Aug., 677–690; 1951, **28,** Oct., 885–898; Nov., 981–986, 992; Dec., 1077–1081; 1952, **29,** Jan., 11–16; Apr., 315–324; July, 581–586, 594; Aug., 709–715; Nov., 965–970, 978; 1953, **30,** Mar., 237–243; 1954, **31,** Feb., 151–157). This series of articles deals in a comprehensive manner with the whole field of rolling theory, drawing very widely on published literature, and including original contributions by the author. The first twelve instalments cover the following subject matter: (1) Contradictions and discrepancies between theory and practice; the conventional theories of Siebel-Karman and developments by Nàdai, Sachs, Ford, and Bland; speed effects in cold rolling. (2) The structure of the "homogeneous" friction hill formulæ; the improved rolling theories of Eichinger and Lueg, and Orowan; general conclusions of existing theories; the analysis of the compression test in relation to rolling. (3) Spreading during rolling; large *versus* small rolls; camber control; resistance to deformation; the distinction between the yield stress curve and the curve of minimum resistance to compression. (4) The effect of speed on friction and strip gauge; and gauge control. (5) The relation between roll material and speed effect; sintered carbide work rolls and general principles of gauge control. (6) Continuous thickness gauges for strip; flying micrometer; X- and Beta radiation gauges; brief outline of gauge control by automatic resetting of rolls. (7) Tension control in mills with clutch driven coilers; the principle of the 'continuous elongator'; the constant-ratio continuous elongator in strip rolling and drawing machines; strip rolling and stretching machines embodying variable-ratio continuous elongators. (8) Forward slip and the effect on it of tension. (9) Beginning of discussion on theory and practice of tension and gauge control in modern production mills; effect of acceleration rate on length of off-gauge strip; properties of the D.C. rolling mill drive; the constant tension D.C. coiler drive; elementary characteristics of a D.C. coiler drive; speed and tension range; constant current tension regulators. (10) Rotating regulator-amplifiers and their application for tension reel control; inertia effects and variable speed drives; effects of IR drop, and IR drop compensation. (11) Speed correspondence between the stands of tandem mills; loss of speed correspondence between stand motors at reduced speed; methods of automatically maintaining constant speed correspondence between tandem mill stands by IR drop compensation. (12) 'Constant percentage speed droop' *versus* 'constant feet per minute droop' operation; tapered tension, and loss of speed correspondence under transient speed conditions and its relation to tapered tension. (119 references).

Timkin Taper Roller Bearings on Rolling Mill Rolls. Rion. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1954, (3), 561–574). After a brief review of the principles and construction of conical roller bearings, the various types made are listed and compared with rollers of different design. Typical arrangements on 2-high, 4-high mills, and a wire train, and some recent applications of note are described. The advantages of this type of bearing include increased production, fewer reheats and considerable savings in power and lubricants.

Use of Nodular Irons or Those Containing Spheroidal Graphite for Rolling-Mill Rolls. Neuville. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (12), 1937–1941). The mechanical and physical properties of these special irons are described. They are twice as strong as normal irons and after a ferritizing heat-treatment have ductilities of up to 20%. Present applications to roll cylinders for rolling sections, sheets, and plates are mentioned. These irons fill the gap between ordinary iron and steel rolls.—A. G.

New Blooming and Billet Mills at Normanby Park Steel Works: Operation of Reconstruction Scheme at Scunthorpe. J. A. Peacock and A. H. Norris. (*Iron Coal Trades Rev.*, 1954, **168,** May 14, 1129–1139). The authors describe in detail the new blooming and billet mills at the Normanby Park Works of John Lysaght's Scunthorpe Works Ltd., and also discuss the auxiliary equipment, means of scale disposal, and lubrication. The plant has an intended ingot capacity of 10,500 tons/week, rolled to sheet-bar, blooms, and billets. Notes on three years' experience in operating the mills are given.—G. F.

Consideration of Heating, Rolling and Annealing as Factors in the Control of Quality Cold Rolled Sheets. H. C. Smith. (*Amer. Iron Steel Inst.: Blast Furn. Steel Plant*, 1954, **42,** June, 653–655). A short account of the rolling-mill practice of the Great Lakes Steel Corp., U.S.A., is given. Particular reference is made to methods adopted to improve and maintain the quality of cold rolled sheets.—B. G. B.

Guides and Strippers for Modern Rod and Bar Mills. F. Starkey. (*J. Iron Steel Inst.*, 1955, **179,** Jan., 58–75). [This issue].

Powering the Fairless Works Two-Stand Tin Temper Mill. C. H. Legler. (*Blast Furn. Steel Plant*, 1954, **42,** May, 521–523). Details are given of the design of the electric drives for this new mill. Owing to restrictions in space the drives had to be unusually compact.—B. G. B.

Shock Fatigue of a Steel Part: Calculation Relating to a Blooming-Shear Stop. L. Gascuel. (*Mét. Constr. Mécan.*, 1954, **86,** May, 415–417). A mathematical treatment of the absorption of shock waves in a solid steel body is first made and the results obtained are applied to the calculation of the dimensions of a stop for use on a blooming-mill shear.

MACHINERY FOR IRON AND STEEL PLANT

How to Increase Power Plant Efficiency. M. Pope. (*Iron Age*, 1954, **173,** Mar. 18, 138–139). It is pointed out that the ratio of electric power to process steam required per net ton of ingot produced. This increased power requirement can be obtained by using passout turbines operating on steam at 900–1500 lb./sq. in.—A. M. F.

Scrap Handling Speeded with Automatic Shear-Baler. W. G. Patton. (*Iron Age*, 1954, **173,** Mar. 18, 143–145). General Motors Corp. have installed two Lindemann balers for bundling steel scrap. The balers are fed by conveyor and each makes three 60-lb. bales measuring 11 × 11 × 6 in. every 2 min. The lid of the baler acts as a shear to skim scrap overfilling the container and two compression rams are used.—A. M. F.

Conveyor Belts: Their Upkeep and Repair. E. Simpson. (*Engineer Foundryman*, 1954, **18,** Apr., 82–84). Details are given of methods of making temporary and vulcanized repairs to rubber conveyor belts.—A. D. H.

A Revolving Crane for Use in Foundries. J. Brzezinski. (*Przeglad Odlewnictwa*, 1954, **4,** (6), 172–174). [In Polish]. A description of the revolving crane designed by the Central Office for the Design of Machine and Foundry equipment in Cracow is given.—V. G.

WELDING AND FLAME-CUTTING

Effect of Hydrogen on the Formation of Porosity on Bead and of Sulphur Crack in Submerged-Arc Welding. M. Okada, T. Kitani, and Y. Ito. (*Osaka Univ., Fac. Eng. Techn. Rep.*, 1953, **3,** Oct., 325–342). [In English]. The cause of bead porosity and cracks growing out of sulphur bands, which occur in the Union-melt submerged-arc welding process were found to be the hydrogen absorbed by the deposited metal from dissociated moisture originally present in the flux. Bead porosity occurred when the absorbed hydrogen exceeded the solubility of the solid metal at the melting point. Sulphur cracks occurred when the deposited metal held excess hydrogen.—J. G. W.

On the Graphitization of Weld Heat-Affected Zone in Carbon Steel. M. Okada and Y. Arata. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1953, **3**, Oct., 311–324). [In English]. The deterioration of the mechanical strength of the heat-affected zone of welds due to graphitization was investigated with the result that preferential graphitization could be explained in terms of the reaction $2Fe_3C \rightarrow Fe_3C + Fe + C$, the occurrence of which was confirmed by magnetic measurements. The presence of chain graphite was established and its mechanism of formation is explained.–J. G. W.

Composition and Shape of Non-Metallic Inclusions in Electric Arc Welds. K. Born. (*Stahl u. Eisen*, 1954, **74,** June 17, 822–831). Isolation of the non-metallic inclusions from submerged arc welds shows that as the Mn/Si ratio in the weld increases, the inclusions coagulate more readily and rise into the slag. As a result of this, the oxygen content of the welds decreases linearly with increasing Mn/Si ratio. Very low oxygen contents should not be aimed at, since at Mn/Si ratios above 3·5, the coagulation rate is so great that very large inclusions are produced and these are trapped by the freezing metal to give fine films or lamellæ. The form of the inclusions is thus more important than the absolute oxygen content. No trace of the inclusions from the base steel is found in the welds; they must obviously have been transferred to the slag. Tests on a weld, made with a twin-head automatic machine on 4-in. plate and with a low oxygen content in the upper part of the seam, showed favourable composition and shape of inclusions. Along with the better crystalline structure that such welds possess, this represents a valuable improvement of quality. Hydrogen flakes in welds made with lime-basic coated electrodes are related to exogenous inclusions, *i.e.*, those arising from the coating.—J. P.

An Investigation on the Accurate Measurement of Internal Stresses at the Upper Surface of Welds by Trepanning. R. A. Huseby and T. McLean Jaspers. (*Lastechn.*, 1954, **20,** May 87–88). [In Dutch]. The authors question the accuracy of the results obtained when measuring the internal stresses in welds by the trepanning method alone. They consider the disc-shaped sample should be reduced in thickness to provide better results.—F. R. H.

International Symbols for Clad Electrodes for Arc Welding Ordinary Constructional Steel and Low-Alloy High-Tensile Steels. (*Lastechn.*, 1954, **20,** Mar., 54–58). [In Dutch.] A code is proposed as a guide for the designation of coated electrodes for manual arc welding by Committee II—Electric Arc Welding of the International Welding Institute. It is in three parts, the first concerns the scope, the second the mechanical properties of the welding material, and the third the welding method.—F. R. H.

MACHINING AND MACHINABILITY

Transgrannular Flaws and Plastic Deformation During the Mechanical Working of the Surface of Iron and Steels. P. A. Jacquet. (*Rev. Mét.*, 1954, **51,** June, 385–400). An experimental study has been made of the microfissures formed in the surface layers of Armco iron and various steels during abrasion and milling, using X-ray and micrographic techniques. The reasons for attributing these discontinuities to open flaws in the material are outlined and the mechanism of abrasion deformation discussed. The practical application of these results is briefly considered.—A. G.

Electric Spark Machining. D. W. Rudorff and H. Drubba. (*Research*, 1954, **7,** June, 216–220). The Sparcatron system of machining metallic surfaces by removal of material by sparks is described; it is widely used, particularly for metals and alloys difficult to machine with conventional tools, and is applicable to such operations as drilling, cutting, and grinding. Some advantages are: Absence of thrust on the work, simplicity of construction of the machines, and no shape restriction to the cutting action. (14 references).—K. E. J.

Waste Handling is Turned to Profits. (*Steel*, 1954, **138,** Apr. 26, 116–117). The equipment installed at Eaton Manufacturing Co., Cleveland, Ohio, to deal with machining chips (which amount to over 26 million lb./year) is described. This included mechanical handling, centrifuge for recovering cutting oil, and a crusher for long chips. The programme for modernizing oil and chip handling paid for itself in 9 months.

Briquetting Press for Metal Swarf. (*Metallurgia*, 1954, **49,** Apr., 189–190). **Swarf Recovery—A Hydraulic Baling Press for Briquetting Cast Iron Machinings.** (*Automobile Eng.*, 1954, **44,** Apr., 154). A description is given of a newly developed hydraulic press of 400 tons capacity by Fielding and Platt, Ltd. The press, which is fully automatic in operation, has been designed specifically for the conversion of small cast-iron borings into high density briquettes suitable for remelting. Production amounts to 300 to 340 briquettes, of 4 to 6 lb. each per hour.—P. M. C.

CLEANING AND PICKLING

Cleaning Metal with Sonic Waves. T. J. Kearney. (*Steel*, 1954, **134,** Apr. 5, 104–105). Methods of cleaning metals with sonic and supersonic waves are briefly reviewed. In the Detrex$_R$ Soniclean process ultrasonic energy is applied to a chlorinated solvent combined with a vapour degreasing cycle. Barium titanate is particularly suitable for use with ultrasonic generators as its low impedance means that transducers require less than 240V.—R. A. R.

A Study on the Mechanism of Organic Inhibitors for Steel in Acid by the Measurements of Local Cell Polarization Curves. Y. Hisamatsu and M. Kanno. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** Mar., 149–152). [In Japanese]. The study concerned mild steel in 10% H_2SO_4 at 40° C., with and without 0·5% diethylaniline as inhibitor. Corrosion is controlled by both the anodic and cathodic polarizations of the local cell, the former being more important; the inhibitor affects both, more particularly the anodic polarization. The results are considered to be applicable to other organic inhibitors.—K. E. J.

The Applications of Blast Cleaning in Steel Processing. V. F. Stine. (*Steel Processing*, 1954, **40,** Mar., 159–163, 194; Apr., 231–236, 253; May, 307–311). The general principles, applications, and economics of sand, shot, cereal grain, and liquid blasting processes are discussed in Part I. Blast cleaning machines are dealt with in Part 2, and the final instalment describes many types of modern cleaning abrasives, their costs, and applications.—P. M. C.

Contribution to the Theory of Electropolishing. C. Wagner. (*J. Electrochem. Soc.*, 1954, **101,** May, 225–228). A mathematical analysis is made of an ideal electropolishing process. Formulæ are derived for the decrease of surface roughness as a function of the recess of the average surface, amount of metal dissolved and the product of current density and time. Conditions for etching are also considered.—A. D. H.

PROTECTIVE COATINGS

Why Go to Thick Protective Coatings? R. R. Pierce. (*Chem. Eng.*, 1954, **61,** Apr., 177–181). Experiments on the anti-corrosion properties of protective coatings, in particular, resistance to hydrochloric acid atmospheres, are reported. For industrial work all coatings under 0·005 in. thick give poor protection, but the value of several types of material applied in greater thicknesses is assessed.—D. L. C. P.

Porosity of Electrodeposited Metals. XII—Measurement of Surface Roughness and Its Change in Exposure. N. Thon, L. Yang, and S. Yang. (*Plating*, 1953, **40,** Oct., 1135–1137). Continuation of a series of articles (*see J. Iron Steel Inst.*, 1954, **176,** Mar., 330). By determining adsorption isotherms, the true surface area of a nickel deposit has been measured after exposure to HCl vapour for 0–60 hr. A rapid initial increase in roughness was found.—A. D. H.

Metal Finishing Practice at the Denham Works of Martin-Baker Aircraft Co. Ltd. (*Sheet Metal Ind.*, 1954, **31,** Apr., 284–287). A well illustrated description is presented of the plant and methods used in a newly established department which undertakes anodizing and dyeing of light alloys; nickel, copper, chromium and cadmium plating; hard chromium plating on light alloys; chromate treatment of magnesium; phosphate treatment of ferrous parts; and black finishes on brass and stainless steel.—P. M. C.

Electrostatic Coating Processes. R. Tilney. (Symposium on Static Electrification, Mar. 25–27, 1953: *Brit. J. Appl. Phys. Supplement No. 2*, s51–s54). Development of three methods of applying static electricity before liquid coating has led to commercial processes for: (1) Introducing atomized coating material into an electrostatic field; (2) removal of surplus from dip-coated parts; and (3) direct application of electrostatically atomized and deposited coating. The principles, methods, and cost of these processes are reviewed.

Stop-Offs in Hard Chromium Plating. A. W. Logozzo. (*Metal Finishing*, 1954, **52**, May, 56–60). Practical points in the application of metallic and non-metallic stop-off materials are discussed and illustrated.—A. D. H.

Nickel-Chrome Plating. An Outstanding Plant at the Works of Vauxhall Motors Ltd. (*Automobile Eng.*, 1954, **44**, Apr., 150–153). This newly installed automatic plant, comprising 22 pairs of process tanks arranged in two parallel rows, is described in detail and illustrated. The principal feature of the plant, claimed to be the most up-to-date in Europe, is the process conveyor system which carries frame loads of components through the complete sequence of dipping operations. A total of 34 sq. ft. can be processed every 3½ min., the current available being 64,000 amp.

Curtain Formation on Galvanized Sheets and Utensils. H.-J. Wiester and D. Horstmann. (*Stahl u. Eisen*, 1954, **74**, June 17, 831–834). Metallographic examination of galvanized sheets exhibiting 'curtains' have shown that the defect is due to thin films of iron above scale. This is due to reduction of the surface of the scale in the annealing furnace.

Flash-Like Defects on Galvanized Sheets. H.-J. Wiester and D. Horstmann. (*Stahl u. Eisen*, 1954, **74**, June 17, 835–838). These defects belong to two different classes, although they go under the same name. Flashes with a rough or 'de-wetted' appearance are caused by surface defects (rolling seams or rolled-in mill-scale). Flashes of fine-grained appearance are caused by hydrogen, occluded in the metal round non-metallic inclusions, leaving the metal during hot-dipping and inducing excessive nucleation of the zinc layer.—J. P.

New Angles for the Galvanizing Line. D. A. McArthur, A. R. Geiszler, and J. Upton, jun. (*Steel*, 1954, **134**, Apr. 5, 100–102; Apr. 12, 102–104). The new 500-ft. continuous strip galvanizing line of Wheeling Steel Corp. at Martins Ferry is described. The product is Softite galvanized steel strip, in coils up to 30,000 lb., or cut pieces. Strip widths of 18 to 36 in., and thicknesses of 0·012 to 0·60 in. are handled. Line speeds vary from 50 to 300 ft./min. Part 1 describes the process sequence, and Part 2 the electrical controls.

The Continuous Galvanizing of Strip Steel by the Sendzimir Process. A. Ollivet. (*Iron Steel Inst. T.M.S.* 214, 1954). This is an English translation of a paper which appeared in *Rev. Mét.*, 1954, **51**, Jan., 17–27 (*see J. Iron Steel Inst.*, 1954, **178**, Sept., 88).

Selected Methods of Heating Galvanizing Kettles. J. Kohlgrüber, J. Leutbecher, and T. Türk. (*Stahl u. Eisen*, 1954, **74**, Apr. 8, 464–474). Methods of heating galvanizing kettles using recirculating or self-circulating waste gases from gas burners or electrical elements are described. Some commercial installations are illustrated and their convenience and the reduction of fuel costs are discussed.—J. P.

Zinc Rich Compounds Give Cathodic Protection. H. L. Grebinar. (*Steel*, 1954, **134**, Mar. 29, 113–114). The nature, methods of application and protective properties of 'Galvicon' are described. This cold galvanizing 'paint' gives cathodic protection to iron and steel, and is a fine zinc powder bonded with vinyl resins.—D. L. C. P.

Tin As a Coating Material. G. Bianchi. (*Met. Ital.*, 1954, **46**, Apr., 141–149). The theory of the reactions which can lead to accompany the corrosion of tin-coated iron and copper are considered from a theoretical point of view, and on the basis of experimental results of other investigators. The author proposes a theory to explain phenomena of the corrosion of tin-coated iron. Consideration is given to anodic and cathodic inhibition of iron and to the conditions which are necessary for developing the inhibition. A critical analysis is made of methods of testing tin deposits. The porosity test should be used to control the quality of tin coatings. (16 references).—M. D. J. B.

Electrolytic Tinning. J. P. Justin. (*Met. Ital.*, 1954, **46**, Feb., 54–61). [In French]. After a brief review of the methods of applying tin to metal surfaces, the author discusses the advantages of electrolytic tinning, particularly where corrosion is liable to be heavy. Different electrolytes, production methods, and qualities of the surfaces produced are considered.—M. D. J. B.

Electrolytic Deposits of Tin Alloys. J. W. Cuthbertson. (*Met. Ital.*, 1954, **46**, Mar., 85–90). [In French]. The author describes the work carried out at the Tin Research Institute on the electrolytic deposition of tin alloys. A theory for the electrolytic deposition of two or more metals is put forward and the practical results obtained with tin–zinc, tin–copper, tin–nickel, tin–cobalt, and tin–antimony are described. The effects of organic additions are also examined.—M. D. J. B.

The Removal of Tin–Lead Alloys from Tinned Iron. V. P. Kochegin. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (1), 51–54). [In Russian]. The separation of a tin–lead alloy from tinned iron by chemical solution of the alloy and its subsequent electrodeposition was studied. Pure alloys containing 11, 17, and 22% of lead were taken for the investigation of their solubility rates in potassium hydroxide solutions with additions of metanitrobenzoic acid as an accelerator. The solubility rates of tin–lead alloys increase with increasing temperature aud concentration of potassium hydroxide solutions. Additions of metanitrobenzoic acid in amounts up to 20 g./l. increase the solubility rates, but higher concentrations decrease the velocity of solution of these alloys.—V. G.

The Reaction of Solid Iron with Molten Aluminium Alloys Containing Zinc. K. Schneider and H. Kessler. (*Metall*, 1954, **7**, Aug., 608–610). Experiments have shown that molten aluminium containing 6–10% Zn will form at 600–700° C. an aluminium–iron alloy on the surface of solid iron much more rapidly than when no zinc is present. Moreover, the $FeAl_3$ coating which forms has a pitted surface and gives better adhesion to subsequently cast-on aluminium coatings than does the alloy formed when there is no zinc in the aluminium.

Investigation on Metal-Spraying Phenomena. A. Matting and K. Becker. (*Schweissen u. Schneiden*, 1954, **6**, Apr., 127–142). A study was made by high-speed photography of the metal transfer during metal spraying. It was found that, independent of the gas/air ratio, the metal spray is oxidized within the flame. A neutral atmosphere is recommended for preventing this oxidation. Pure metal was sprayed without difficulty but a solidification period was observed with alloys. The particles are accelerated from 5 to 30 mm. in front of the jet, and in the presence of excess oxygen they oxidize rapidly. (57 references).—U. E.

Resurfacing by Means of the Oxy-Acetylene Torch. (*Usine Nouvelle*, 1954, **9**, Jan. 28, 55–56). The process of building up wear-resisting layers is described together with the properties of such layers. The alloys to be used on different base metals, including those for special resistance to wear, are detailed.—A. G.

The Control of Properties of Base Enamels for Steels. K. P. Azarov. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (1), 33–42). [In Russian]. Enamels with and without boric oxide and the influence of various additions on the quality of the finished surface were studied. Base enamels containing no boric oxide differ from those containing it in the following ways: (*a*) They produce surfaces with a strongly developed bubble structure and many burnt spots; (*b*) their high viscosity causes excessive local oxidation of the steel surface; (*c*) their lowered ability to dissolve and disperse iron oxides in the scale causes local supersaturation of the melt; (*d*) their lower wettability of the oxidized metal inhibits the development of a protective film and the sealing of pits; and (*e*) the melt may exert an oxidizing action on the steel. The quality of the enamelled surface can be improved by additions to the enamel of: (*a*) strong fluxes; (*b*) surface active substances (*e.g.*, Cu_2S, FeS, Sb_2S_3, MoO_3); (*c*) reducing agents; and (*d*) protection of the steel surface from excessive oxidation by a special treatment (such as dipping in nickel sulphate solution with thio-urea) before enamelling.—V. G.

Flexure and Fracture of Vitreous Enamelled Steel Strips. C. J. Rodman and F. J. Shollenberger. (*Amer. Ceram. Soc. Bull.*, 1954, **33**, Apr., 105–107). An investigation of the strength of different gauges of steel, as used in the manufacture of steel sanitary ware, and the accompanying effect of enamel coatings thereon is reported. The strength increased approximately as the cube of the sum of the steel thickness and one half the enamel thickness. The enamel-fracture point and the elastic limit of the specimens were also noted.—D. L. C. P.

A Study of Hairlining. J. E. Cox and A. S. Andrews. (*J. Amer. Ceram. Soc.*, 1954, **37**, Apr., 186–191). A simple and reliable test devised to show the hairlining tendencies of enamels is presented. The stepwise process of hair-line formation is described, with the aid of photographs and photomicrographs of enamel surfaces and cross sections. The effects of ground coat and cover coat variables, and the significance of proper firing schedules are presented and discussed.

Enamel Finishes. W. E. Ebel. (*Bull. Inst. Vitreous Enamellers Ltd.*, 1954, **4**, May, 4–6). The author reviews the recent

developments in the applications of those enamels at present being used by the enamelling industry. Particular reference is made to the expanding use and methods of applying titanium enamels.—L. E. W.

One Coat White Enamel. J. Semple. (*Inst. Vitreous Enamellers Ltd., Bull.*, 1954, **4**, Mar., 5–10).

Stability of Colours in Titania-Opacified Enamels. B. K. Niklewski and R. H. Ashby. (*Inst. Vitreous Enamellers Ltd., Bull.*, 1954, **4**, May, 7–15).

Electrostatic Detearing Improves Dip-Coating Quality. J. J. Orbzut. (*Iron Age*, 1954, **173**, Feb. 4, 153–155). A brief description is given of the application of electrostatic detearing to provide smooth, uniform coatings on dip-coated parts. A special electrode arrangement at high electrical potential attracts the paint from drain points in a matter of seconds, eliminating soft paint films and wrinkles.—A. M. F.

Ceramics for High Temperatures. A. Pechman. (*Chem. Eng.*, 1953, **60**, Nov., 186–190). A brief survey of the ceramic materials available for use at high temperatures is made. The recent developments in ceramic coatings for the protection of metals and cermets are discussed.—B. G. B.

Two New High Temperature Coatings. A. Pechman. (*Mat. Methods*, 1954, **39**, Apr., 94–96). The application of a nickel-magnesia cermet to after-burner liners, exhaust systems, and other hot parts of aero-engines is described. A flame-spraying technique is used, the cermet being liquefied and applied to the metal as a thin coating by blowing through an oxy-acetylene flame at 5500° F. Performance tests at temperatures up to 1800° F. are also described in which a new ceramic coating, type A-418 American National Bureau of Standards, is shown to exhibit excellent protective qualities.

An Examination of Reboiling in Vitreous Enamels. J. H. Keeler, G. P. K. Chu, and H. M. Davis. (*Sheet Metal Ind.*, 1954, **31**, Mar., 233–240). A comprehensive series of experiments is described, designed to study the factors influencing the phenomenon of reboiling and to determine its cause. Reboiling is the sudden appearance of blisters on vitreous enamel coats that may occur on second or subsequent firing. It is concluded that reboiling of vitreous enamels on steel results from the release of gaseous hydrogen trapped in the metal. (12 references).—P. M. C.

Porosity of Sprayed Coatings. III—Impregnation and Organic Finishing of Sprayed Coatings. D. de Paauw. (*Electroplating*, 1954, **7**, Jan., 35–38). Conclusion of a series of articles (*see J. Iron Steel Inst.*, 1954, **177**, Aug., 476). Processes for impregnating sprayed coatings with varnishes, plastics and inorganic sealing compounds are described. Improvement in corrosion resistance is stated to occur. The choice of paints and methods of painting are discussed. (33 references.).—A. D. H.

POWDER METALLURGY

Metal Supplies and Powder Metallurgy To-morrow. H. W. Greenwood. (*Metallurgia*, 1954, **49**, Mar., 135–136). The rate at which high grade deposits of metal ores are being used up increases the importance of methods for processing lower grade materials. Reference is made to the application of hydro-metallurgical and ion exchange methods and attention drawn to the fact that in certain processes metal powders suitable for use in powder metallurgy are produced.—B. G. B.

Comparison of the Microscopical and Microradiographic Methods of Examination in the Study of the Diffusion during the Sintering of Iron Powders of Different Origin. G. Cizeron. (*Métaux-Corrosion-Indust.*, 1954, **29**, Apr., 167–180). The two methods have been used to examine samples having different mechanical properties. The microradiographic method has been found very useful in investigating sintered iron powders, particularly for estimating the dimensions and form of the porosity. Samples prepared from carbonyl, sponge, electrolytic, and atomized iron have been examined by these two methods to find the influence of the method of preparation of the iron on the structure and distribution of pores.—B. G. B.

Infiltration Improves Properties of Metal Powder Parts. J. L. Everhart. (*Mat. Methods*, 1954, **39**, Apr., 88–90). The many benefits obtainable by infiltration of different materials into porous sintered components are described. Three distinct types of infiltration are considered: (*a*) No wetting or solubility, *e.g.*, iron compacts infiltrated with plastics to promote better electroplating qualities; (*b*) wetting but no solubility, *e.g.*, compacted tungsten electrical contacts infiltrated with copper or silver to improve conductivity; (*c*) wetting and solubility enabling improvements in properties to be obtained by subsequent heat-treatment, *e.g.*, iron compacts infiltrated with copper for jet engine stator blades.—P. M. C.

PROPERTIES AND TESTS

Interpretation and Application of Inspection Test Data. P. V. Faragher. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 217–218). The relation between inspection test results and expected service properties is briefly discussed. The method of treating accumulated data on one material to arrive at specification values is reviewed.—P. M. C.

Interpretation of Creep and Long-Time Test Data. J. Marin. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 207–212). The log-log method of extrapolating creep test data is described. The derivation of the equation $e = DS^m + BtS^n$, where e = total creep deformation for a time t in terms of the stress S and experimental constants D, B, m, and n, is outlined. Other empirical creep-time and creep-stress equations are tabulated, and the interpretation of stress-rupture time test data is discussed. Experimental creep constants, including those required in the above equation, are tabulated for various steels and cast iron.—P. M. C.

Relation Between Stress Analysis and Fatigue of Metals. R. E. Peterson. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 199–206). The qualitative and quantitative usefulness of knowledge of elastic stress distribution in connection with fatigue behaviour of machine parts is discussed. The point of inception and direction of propagation of fatigue cracks can often be derived from photoelastic or brittle lacquer patterns, whilst theoretically or experimentally derived stress concentration factors at notches and fillets enable the results of standard fatigue tests to be applied to the design of large members. Several examples of the application of stress concentration factors are worked out. (11 references).—P. M. C.

Improved Brittle Coatings for Use Under Widely Varying Temperature Conditions. F. N. Singdale. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 173–178). The Magnaflux Corp. of America has developed, under the name of " Stresscoat All-Temp," a range of vitreous enamels for use as stress indicators over the range of sensitivities from 4000 to 50,000 lb./sq. in. (for steel). These enamels possess the advantages of being useful over a wide range of temperatures and are resistant to water and oils. Brief details are given of typical applications.—P. M. C.

Crack Density Studies in Stresscoat. A. J. Durelli and S. Okubo. (*Proc. Soc., Exper. Stress Anal.*, 1954, **11**, (2), 153–160). The usual method of determining strains by means of the brittle coating technique requires the knowledge of the coating strain sensitivity and of the load necessary to crack the coating at any particular point. It has been suggested that the crack density may be used also to determine strains. In this paper an attempt is made at a systematic study of the crack density in " Stresscoat " as a function of the unidimensional state of stress in the material under the coating.—P. M. C.

Application of Silver-Painted Slip Rings for Strain Gauge Circuits. D. K. Wright and J. R. Jeromson, jun. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 139–140). A description is given of a method of applying silver paint to a suitably insulated shaft in such a way as to make slip rings for use in strain gauge circuits. G.E.C. Glyptal No. 1201 Red Enamel is used as the insulation coating, and DuPont Type A, No. 4922 Silver Conductive Coating as the ring material. Special attention must be paid to the thorough drying-out of both the insulation and the painted rings.—P. M. C.

Determination of Residual Stresses in Lightly Rolled Thin Strip. B. B. Hundy. (*J. Iron Steel Inst.*, 1955, **179**, Jan., 23–29). [This issue].

A New Dynamic Creep Testing Machine. Y.-H. Pao and J. Marin. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 107–114). A four-unit machine is described in which specimens may be subjected to a fluctuating load, consisting of a mean static load, and an alternating load. The mean static load is maintained constant by dead weights acting through a lever arm connected to the top of the specimen. The alternating load is applied by a motor-driven eccentric

attached to one end of a spring, the other end being attached to the bottom of the specimen. The machine was developed for testing plastics and is of comparatively low load capacity. The maximum load for static tests is 2500 lb. and the allowable crest load value for a dynamic test decreases with frequency, being only 600 lb. at 30 reversals/sec.—P. M. C.

Experimental Stress Determination Within a Metal During Plastic Flow. E. G. Thomsen and J. T. Lapsley, jun. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 59–68). A graphical stress analysis is presented which permits calculation of stress distribution within the plastic zone of a metal. The analysis is based on an experimental strain analysis for a non-work-hardening metal from a stepwise deformation process. It is shown that the stress distribution may be calculated for the case where the load at a particular section of the metal is known and for the more general case where only the hydrostatic tension is known at one point in the metal. The former case is illustrated by an inverted extrusion of lead, the incremental strains on a diametral plane being determined from an inscribed square grid pattern.—P. M. C.

Network Representation of Elastic Problems in Cylindrical Co-ordinates. W. A. Gross and W. W. Soroka. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 45–58). The equivalent circuits developed by Gabriel Kron to represent the partial differential equations of the theory of elasticity are extended in this paper to the three-dimensional problem in cylindrical co-ordinates.—P. M. C.

Smplified Measurement of Residual Stresses. J. L. Waisman and A. Phillips. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 29–44). A rapid technique is described for measuring the residual stress gradient developed in plates by various manufacturing operations. The method involves the removal by chemical solution of layers from one surface of a specimen and the simultaneous measurement of curvature changes accompanying the removals. A fixture for making the measurements of thickness and curvature with dial gauges while the specimen is immersed in the etching solution is described. Specimens are 4 in. by 1 in. and approx. 0·1 in. thick. An accuracy of $\pm$ 5% is quoted for the stress measurements. Charts are presented for rapid calculations of stress patterns, and an appendix deals with the theoretical derivation of the formulæ used in the calculations.—P. M. C.

Control and Programming of a 200,000-Pound Fatigue Machine. H. C. Roberts and V. J. McDonald. (*Proc. Soc. Exper. Stress Anal.*, 1954, **11**, (2), 1–10). The machine under consideration has been built to test large-scale specimens, especially built-up sections, and bolted and riveted joints. It can apply a cyclic load about any desired mean load approximately three times per second through a lever system driven by an eccentric. A system of control and programming of the load pattern is described; it is based on an inductive strain gauge attached to a main column of the machine. Corrective signals are fed to a vibration galvanometer, the light from which actuates photo-cells. Signals from the photocells operate relays which in turn control motors for adjusting the mean and cyclic loads.—P. M. C.

Rapid Method for the Determination of the Fatigue Limits of Metals and Alloys. G. Vidal. (*Recherche Aéronaut.*, 1953, July-Aug., 49–54). For the routine testing of metals the usual lengthy test procedures are not suitable and therefore a number of rapid fatigue tests suitable for routine use have been developed and these are considered. Methods based on the measurement under load of the rate of heating of the sample, the sag of a loaded rotating bar, the change in the electrical resistance, minimum coefficient of expansion, and maximum magnetostrictive force are described together with the Prot method using progressive increases in load. (17 references).—B. G. B.

Study of Fatigue under Progressive Load Carried Out in the United States. M. Prot. (*Rev. Gén. Méc.*, 1954, **38**, May, 149–150). Recent work on this method of fatigue testing (developed originally by the author) which has been carried out in America is discussed.—B. G. B.

On the Theory of Fatigue Failures of Metals. T. Nishihara, and K. Endo. (*Tech. Reports, Engineering Research Inst., Kyoto University*, 1952, **2**, Oct., 171–186). [In English]. A theory of fatigue failure under combined stresses is proposed, according to which failure occurs when $\sigma_1 - \sigma_3/m_0 = k_t$, where σ_1 and σ_3 are the largest and smallest principal stresses respectively, k is the fatigue limit in alternating tension, and m_0 is characteristic of the material (equal to unity for brass, and four for cast iron, steels occupying intermediate values which increase with carbon content). In the event of the largest principal stress being compressive, the criterion of fatigue failure is $\sigma_3 - \sigma_1/m_0 = k_c = m_0 - k_t$, where k_c is the fatigue limit in alternating compression. Fatigue tests results reported in the literature and data determined by the authors on 0·07%-C steel are shown to be in good accord with the theory.—J. G. W.

Effect of Dimensions and Hardening Temperature on the Hardness and Toughness of Case-Hardening Steels. H. Kiessler and E. Kunze. (*Stahl u. Eisen*, 1954, **74**, June 3, 768–772). A statistical survey has been conducted on the hardness of some Mn–Cr and Cr–Ni steel discs of various thicknesses after quenching. Recommendations are made for the modification of the current German standard specification for case-hardening steels. It has been found by tests on hardened discs of different thicknesses that, with decreasing thickness (increasing hardness), the impact strength remains constant or even increases.—J. P.

475° C. (885° F.) Embrittlement in Stainless Steels. A. J. Lena and M. F. Hawkes. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200** : *J. Met.*, 1954, **6**, May, Section 2, 607–615). The authors have studied the embrittlement at 475° C. of high-purity 28%-Cr and commercial 31%-Cr stainless steels by observation of changes in microstructure, hardness, tensile properties, electrical resistivity, and *X*-ray diffraction effects. The results indicate that lattice strains are necessary to cause this embrittlement, which is felt to be due to the accelerated formation of an intermediate stage in the formation of the σ-phase under the influence of these strains.—G. F.

An Automatically Recording Magnetic Balance. T. Hirone, S. Maeda, and N. Tsuya. (*Sci. Rep. Res. Inst. Tohoku Univ.*, Series A, 1954, **6**, (1), 67–76). [In English]. A new automatic recording magnetic balance for plotting magnetization-temperature curves is described.—J. G. W.

Errors in the Measurement of Watt Losses of Electrical Sheets on Epstein and Ring Samples. R. Ochsenfeld. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 293–297). The errors in the measurement of watt losses on the Epstein apparatus, which are actually caused by non-uniform magnetization of the samples, have been determined by means of a corrected loss-induction curve, and found to be 4–5%. Comparison of measurements on ring and Epstein samples is made difficult by lack of knowledge of the distribution of radial magnetization of the ring.—J. P.

Ultrasonics as a New Non-Destructive Means of Testing Materials in the Precision Mechanics Field. R. Pohlman. (*Microtecnic*, 1954, **8**, (2), 84–88). The limitations of the echo method of ultrasonic flaw detection for material thickness below about 6 mm. are outlined. A description is given of a new instrument, the 'Sensometer,' developed by Dr. Lehfeldt and Co., Heppenheim, Germany, for testing small and intricate parts such as wires, bands, welded seams, and thin sheet. Continuous ultrasonic waves are used and the energy passing through the part is measured and indicated by a meter. A warning lamp or other type of signal is operated if the transmitted energy falls below a preset value due to the influence of flaws.—P. M. C.

Investigations of the Efficiency of a 31-MeV-Betatron for the Radiography of Steel. H. Möller, W. Grimm, and H. Weeber. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 279–291). The most suitable types of intensifying screens for use on the Brown Boveri 31-MeV-betatron and the general conditions for obtaining the most useful information about defects in steel have been determined.—J. P.

A Simple Apparatus for a Magneto-Inductive Sorting Test. K. Matthaes. (*Z. Metallkunde*, 1954, **45**, July, 428–429). A simple and inexpensive instrument is described for sorting, under given conditions, mixed batches of steel.—L. D. H.

Inexpensive X-Ray Detectors. U. W. Arndt. (*J. Sci. Instruments*, 1954, **31**, May, 192–193). A simply constructed X-ray detector is described, using a Geiger-Muller counter operating at 650V. connected to a mirror galvanometer. Dry batteries provide the high-tension supply, and low counts of a few hundred per minute can be measured with a galvanometer with a period of 10 sec., the response of which is linear up to about 1000 counts/sec. The counter, as it is halogen-quenched, can also be used, for low intensities, below its Geiger starting voltage.—L. D. H.

The Lattice Component of the Thermal Conductivity of Metals and Alloys. P. G. Klemens. (*Australian Journal of*

Physics, 1954, **7**, Mar., 57–63). Makinson's theory has been re-examined at low temperatures and related to the variation of lattice conductivity with electron concentration. Measurements on Cu—Ni alloys can be reconciled with the theory if certain assumptions are made, and work is proceeding with other alloys.—J. O. L.

Materials for High Temperature Service. H. R. Clauser. (*Mat. Methods*, 1954, **39**, Apr., 117–132). A broad and general survey is presented of the materials commonly used at temperatures above 300° F. Properties, compositions, and range of applications of super alloys, irons and steels, light metals, ceramics and cermets, plastics, and copper and copper alloys are discussed and tabulated. In the second of the above groups the article gives much information on cast and malleable irons, molybdenum and chromium–molybdenum steels, straight chromium and austenitic steels, and special heat-resisting casting alloys. (11 references).

Results of Creep Tests of up to 100,000 Hours Duration at 500° C. on Low-Alloy Steels. A. Thum and K. Richard. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, Aug., 235–245). Long duration creep tests were carried out on 12 steels (seven low alloy Cr–Mo steels with and without nickel or vanadium; two Cr–V steels; one Cr–Mo–V–W steel; one 18–20%-Cr steel with 1% Mo; one 18/8 stainless steel with 0·67% Ti) at 500° C., because the occurrence of brittle fractures had shown that the usual DVM creep limit was not a sufficiently good criterion for satisfactory service. The effect of alloying elements and heat-treatment on the tendency to embrittlement was shown. Other phenomena studied were graphite precipitation in unalloyed and molybdenum steels and the possibility of prolonging life by heat-treatment at regular intervals.—H. R. M.

The Creep Deformation of Metals under Discontinuous Stress and Temperature Conditions. A. J. Kennedy. (*Mech. World*, 1954, **134**, Feb., 54–57). The author discusses the effects produced on the creep strain of materials, particularly metals, by interrupting or varying the applied stresses. It is shown that greater creep strains for a given duration of test can be achieved by removing the stress for regular periods than by applying it continuously throughout the test.—D. H.

Stress Required to Hot-Tear Plain Carbon Cast Steel. U. K. Bhattacharya, C. M. Adams, jun., and H. F. Taylor. (*Amer. Found. Soc. Preprint* 78, 1954). Hot tearing was investigated using a flanged casting which could be restrained from free contraction by two water-cooled rigid bars moulded between the flanges. Strain gauges on the bars enabled the total load on the casting to be measured, and a gap in the restraining mechanism permitted all the temperature of stressing to be varied. It was found that hot tearing could occur at temperatures down to 930° C. and would follow the austenite grain boundaries. High sulphur and high phosphorus steels were more susceptible to tearing than ordinary commercial steels and steels treated with 0·025% or 0·05% aluminium showed lower tearing stresses than those treated with 0·10% aluminium. Deoxidation with 0·2% titanium and 0·1% aluminium was most effective in raising the tearing stress.

Theoretical Aspects of Oxygen in Cast Iron. B. B. Bach. (*Amer. Found. Soc. Preprint* 6, 1954). The effects of carbon, silicon, manganese, and phosphorus on the equilibrium oxygen content of liquid iron are reviewed; with the possible exception of phosphorus, all the elements reduce the oxygen content of the metal. Slag–metal reactions are excluded from the discussion which is confined to the relevent gas–metal equilibria. The limitations of the data are pointed out.—B. C. W.

Solubility of Oxygen in Alpha Iron. A. V. Seybolt. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, May, Section 2, 641–644). The author has determined the solubility of oxygen in high-purity α-iron in the temperature range 700–900° C. The solubility varies from about 0·008% at 700° C. to about 0·03% at 900° C., the data being quite reproducible and rationalized by the Van't Hoff equation.

Impact Transition Temperatures of Some Pearlite-Free Mild Steels as Affected by Heat-Treatments in the Alpha Range. A. Josefsson. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, May, Section 2, 652–659). The author has carried out Charpy impact tests on low carbon steels and shows that the impact transition temperatures of 0·01–0·02%-C steels is strongly influenced by the cooling rate in the α range, quenching from A_1 causing a very low transition temperature even after strain-ageing. This effect is absent in titanium-stabilized steels and 0·05%-C steels. The low transition temperatures are believed to be due to a finely dispersed precipitate containing carbon, and possible mechanisms are discussed.—G. F.

LD Acceptance Tests. (*Vereinigte Österreichische Eisen- und Stahlwerke*, Linz, Aug. 18, 1953). [In German and English]. This book records on numerous data sheets with many original photographs, the acceptance tests carried out on LD shipbuilding steel in the presence of representatives of the American Bureau of Shipping, Bureau Veritas, Det Norske Veritas, Germanischer Lloyd, Lloyd's Register of Shipping, and Registro Italiano Navale. [*Note:* LD = Linze Düse = Linz nozzle, this being the nozzle through which oxygen is blown downwards on to the surface of the steel in the converters at Linz].

Properties of LD-Steels. H. F. Hauttmann. (*One Year Oxygen Refining Process*: VÖEST Linz-Donau, 1954, 17–34). [In English]. The author first gives a description of the mechanics of the LD process, showing that a converter with a hemispherical bottom is necessary, hence the process is not applicable to open-hearth practice. He then gives a comprehensive survey of the applicability of the steel to various purposes, the results of chemical, physical, and metallurgical tests being given. The steel is claimed to be suitable for ordinary structural purposes, especially those requiring high resistance to cleavage fracture. It is said to be preferred to open-hearth quality for cold rolling requirements.

Chromium-Manganese Stainless Steels: Where They Stand Today. J. L. Everhart. (*Mat. Methods*, 1954, **39**, Mar., 92–94). The continuing shortage of nickel is reviving interest in these substitute steels, which have properties that compare favourably with those of Cr-Ni steels. The limited usefulness and particular applications of 16/16/1 Cr–Mn–Ni, 17/6/4 Cr–Mn–Ni, 18/10/4 Cr–Mn–Ni, and 16 15/6/6 Cr–Ni–Mn–Mo stainless steels are briefly discussed. Some data on mechanical properties are also given. (10 references).

The Influence of Carbon and Manganese on the Properties of Semikilled Hot Rolled Steel. F. W. Boulger and R. H. Frazier. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, May, Section 2, 645–652). The authors have studied the effects of carbon (0·14–0·34%) and manganese (0·20–1·50%) on grain size, tensile properties, and notched-bar properties of laboratory induction-melted semikilled steels, hot-rolled to ¾ in. plate. The ductile-brittle transition temperature is raised by increase in carbon and lowered by increase in manganese, whilst increases in either element increase the McQuaid-Ehn grain size and tend to refine the ferritic grain-size of the hot-rolled material. The interrelationship of these properties is discussed.—G. F.

The Case for Blue Ribbon Steels. (*Steel*, 1954. **134**, May 10, 114–117). The circumstances in which to employ an alloy-steel, the properties imparted to a steel by alloying elements, and the type of steel to choose in relation to hardenability, etc., are explained with examples. A list of new and improved alloys gives analysis and properties for many steels available in the U.S.A.—D. L. C. P.

Effect of Graphite Flake Size on Tensile and Fatigue Properties of Grey Cast Iron. R. W. Lindsay and J. H. Hoke. (*Amer. Found. Soc. Preprint* 20, 1954). Grey cast irons with different graphite flake sizes were produced from the same cupola heat by the use of Si–Mn–Zr as an inoculant and by casting into bars of different diameters. To ensure that the graphite flake size was the only variable, the tensile and fatigue specimens were machined from quenched and tempered blanks and not from the original as-cast bars. The mechanical test results showed that both tensile strength and endurance limit were lowered when the graphite flake size was increased, and that the apparent modulus of elasticity in tension also fell. The size of the graphite flakes showed a considerable increase as the casting diameter was raised from 1 in. to 3 in. but to increase only slightly for larger castings.—B. C. W.

Standards for Grey Cast Iron. M. Itzel. (*Gjuteriet*, 1954, **44**, May, 84–86). [In Swedish]. Problems encountered when trying to formulate the new Swedish standards for four grades of cast iron (having minimum tensile strengths of 15–30 kg./sq. mm.) are described. A class interval of 5 kg./sq. mm. has been chosen to allow for inaccuracies during testing. A table compares test bar diameter and minimum tensile strengths which have been standardized in England, France, Switzerland, Sweden, Germany, and U.S.A.—G. G. K

METALLOGRAPHY

Cold Electron Emission of Metal Surfaces (Exoelectrons). K. Lintner and E. Schmid. (*Z. Metallkunde*, 1954, **45,** May, 276–285). A survey is made of the phenomena of electron emission from cold worked and chemically treated metal surfaces, their measurement by Geiger counters, and their theoretical significance. Decay curves were drawn for several metals, including iron, and the effect of heating the specimens shown, by the use of a needle counter. Under certain conditions, after allowing a suitable time to elapse before heating the sample, a sharp rise in the count was observed at temperatures characteristic for each metal—167° C. in the case of iron.—L. D. H.

Development of and Results Obtained from High-Temperature Metal Microscopy. G. Reinacher. (*Z. Metallkunde*, 1954, **45,** July, 453–458). The development of high temperature hot-metal microscopy during the present century is outlined. The application to metallographic problems is bound up with the development of the hot stage; the Leitz vacuum hot-stage attachment is described. Examples of investigations into structural changes are given, and it is pointed out that some work has been done on liquid processes, using the instrument.—L. D. H.

The Growth of Grains Observed by an Emission Microscope. G. W. Rathenau and G. Baas. (*Métaux-Corrosion-Indust.*, 1954, **29,** Apr., 139–150). The employment of this technique, to study grain growth in steels is described. The method utilizes the electrons emitted from a sample when it is heated to form an image, as in the conventional electron microscope. The growth of face-centred cubic crystals in an Fe–Ni alloy in the form of a rolled sheet having a preferred orientation has been examined. The $\alpha \rightarrow \gamma$ transformation in Fe–Si alloys and the growth of pearlite in eutectoid steel have also been investigated. A number of photomicrographs are reproduced. (16 references).—B. G. B.

Metallography with the Electron Microscope. J. Nutting. (*Metal Treatment and Drop Forg.*, 1954, **21,** May, 243–250). The development of the electron microscope and its capabilities are described. Metal shadowing, replica techniques, and direct examination using scanning-type and reflection microscopes are outlined. The aims and limitations of electron metallographic methods are discussed. (18 references).

Diffraction Grating Copies for Electron Microscope Calibration. Betty E. Williams. (*J. Sci. Instruments*, 1954, **31,** May, 190). Gelatine grating copies from a plane diffraction grating of 15,000 lines/in., as supplied by the National Physical Laboratory, are described, and their use for calibrating the magnification of electron microscopes is discussed.

A Precision 19 cm. X-Ray Diffraction Camera. J. Adam. (*J. Sci. Instruments*, 1954, **31,** Apr., 131–132). A 19-cm. X-ray diffraction camera is described, in which inaccuracies caused by faulty film mounting and eccentricity in setting the specimen are obviated. The difficulty in using knife edges as reference markers in a large diameter camera is overcome by the use of reference marks.—L. D. H.

A Simple Method of Obtaining Low-Temperature X-Ray Diffraction Photographs. S. C. Wallwork and T. T. Harding. (*J. Sci. Instruments*, 1954, **31,** May, 163–164). Constant low temperatures in the range -30 to $-60°$ C. can be obtained and maintained for at least 1 hr. by the use of a vacuum flask containing liquid air, boiled by electrical heating. The gas is conveyed to the crystal, mounted on an oscillation goniometer, by a rubber tube. The method of controlling the temperature is described; no trouble with ice formation was encountered, even in humid atmospheres.—L. D. H.

A Combination of Electron Microscopy and Diffraction. S. Yamaguchi. (*J. Sci. Res. Inst.*, 1953, **47,** Dec., 202–204). A method of focussing the electron microscope has been evolved which depends on electron diffraction instead of observing the image. It is particularly valuable for making microphotographs of weak images or in cases where the electron beam can cause deterioration of the sample.

A Simple Form of Flat-Field Microscope Objective. W. S. S. Blaschke. (*J. Sci. Instruments*, 1954, **31,** May, 173–174). The construction is described of a flat-field microscope objective, which by using a thick meniscus, permits a comparatively simple design to be adopted; this has the advantage of extending the useful field and retaining a high numerical aperture.—L. D. H.

The Question of Magnetically Orientated Structures in Permanent Magnets. K. J. Kronenberg. (*Z. Metallkunde*, 1954, **45,** July, 440–448). Investigations are described, using an electron microscope, and oxide layer replicas, into the structure of an Fe–Co–Ni–Al–Cu alloy cooled through the range 950–750° C. in a magnetic field. The results obtained are discussed, and are found to confirm in the main the results previously obtained by Heidenreich and Nesbitt (*see J. Iron Steel Inst.*, 1953, **173,** Mar., 314).—L. D. H.

Relation of Properties to Microstructure. (*Amer. Soc. Metals*, 1954, 1–270). This seminar was held during the 35th National Metal Congress and Exposition at Cleveland, Ohio, on Oct. 17–23, 1953. The papers presented were:

Structure-Sensitive Properties. J. H. Hollomon. (1–15). The effect of structural defects, such as grain boundaries, disclocations, impurity atoms, vacancies, and particles of second phase, on the electrical, mechanical, and magnetic properties of crystalline solids is discussed. (11 references).

The Effect of Grain Boundaries on Mechanical Properties. M. Gensamer. (16–29). Crystallographic translation and grain boundary shear are discussed in relation to temperature, grain size, and impurities. (27 references).

Principles of Solution Hardening. E. R. Parker and T. H. Hazlett. (30–70). Work published on solution hardening is correlated and critically reviewed. A further theory of the possible mechanism of solid solution hardening is suggested. (44 references).

Effect of Dispersions on Mechanical Properties. J. E. Dorn and C. D. Starr. (71–94). The authors review published work on the mechanical properties of polycrystalline metals, two-ductile-phase alloys, hard-ductile-phase alloys, and alloys in which a hard phase is distributed in a ductile phase. (33 references).

Theories of Dispersion Hardening. E. W. Hart. (95–107). The dispersion hardening theories of Mott and Nabarro, of Orowan, and of Fisher, Hart, and Pry are critically reviewed and analysed with reference to experimental evidence. (11 references).

Structure and Alloy Design. A. D. Schwope. (108–130). The author discusses the effects of alloying and of the subsequent structures on the strength of metals. (33 references).

Interactions of Dislocations and Solute Atoms. A. H. Cottrell. (131–162). Types of interactions are discussed under the headings of elastic interaction, electrical interaction, chemical interaction, and geometrical interactions. The effects of interactions are then considered. (75 references).

The Relation of Microstructure to Brittle Fracture. J. R. Low, jun. (163–179). The causes and propagation of brittle fracture are discussed in relation to microstructure. The conditions necessary for initial microcracking are described. (19 references).

Effect of Microstructure on Corrosion. H. H. Uhlig. (189–208). The author shows that corrosion may or may not be affected by microstructure, depending on the factors controlling the corrosion reaction. (23 references).

Relation of Magnetic Properties to Microstructure. L. J. Dijkstra. (209–232). Secondary ferromagnetic properties, such as permeability, coercive force, and remanence, unlike the primary properties, are dependent on microstructure. The author discusses the effect of grain size and shape, and of dispersed particles on the coercive force. (11 references).

Structure and Coercivity. J. F. Libsch and G. P. Conard. (233–259). The authors discuss the influence of porosity, non-magnetic inclusions, grain boundaries, orientation effects, composition effects, precipitation, and crystal order on the coercivity of ferro-magnetic alloys. The effect of particle size on the coercivity of permanent magnets, produced by powder metallurgy methods, is considered. (65 references).—J. E. J.

A New Method of Forming Etch Figures on the Surface of Iron. J. Bardolle and J. Moreau. (*Compt. Rend.*, 1954, **238,** Mar. 29, 1416–1418). To facilitate the determination of the orientation of crystal faces on an iron surface an electrolytic method of developing etch figures has been perfected. The specimen is made the anode in an aqueous solution of ammonium thiocyanate at a current density of 1·5 milliamp./sq. cm. for a period of about 4 min..—A. G.

Improvement in the Oxidation Method Enabling True Austenite Grains to be Revealed in Steel. A. Kohn. (*Rev. Mét.*, 1954, **51**, Feb., 129–137). The method, which overcomes the disadvantages of the cementation procedure, utilizes the preferential diffusion of oxygen along the austenite grain boundaries. The specimen, previously polished in argon, is heated to effect a short period of oxidation after austenitization and then quenched. A light repolishing and etching reveals the original austenite boundaries.—A. G.

On the Mechanism of Grain Growth in Metals, with Special Reference to Steel. D. G. Cole, P. Feltham, and E. Gillam. (*Proc. Phys. Soc.*, 1954, **B67**, Feb. 1, 131–137). The rate of grain growth during isothermal austenitizing in plain eutectoid carbon steel was studied by a thermal etching method. An equation relating the mean and instantaneous diameters with time is developed on the assumption that growth is controlled by interfacial tension at the boundaries. The value of H of 30 kg. cal/g.-atom is close to the self-diffusion activation energy and that calculated by damping methods. (24 references).—K. E. J.

The Particle Size of Iron Nitride Precipitated from α-Iron Supersaturated with Carbon and Nitrogen. W. Köster and L. Bangert. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 231–238). Pure Fe–C, Fe–N, iron, and Fe–C–N alloys and a Bessemer steel have been aged at temperatures between 50° and 250° C. after furnace cooling from just over the Ac_3 point or quenched from various temperatures below the A_1 point. The precipitation of carbon and nitrogen individually from the binary alloys, and together from the ternary alloys, has been followed by damping measurements alone, by simultaneous damping and coercivity measurements, and by optical and electron microscope examination, and the amount and size of the precipitate determined. It is shown that carbon and nitrogen precipitate from the doubly supersaturated solution independently of each other. The size of the nitride needles is, however, smaller the greater the carbon supersaturation. In these circumstances, the growth of the nitride needles is hindered by the presence of the numerous submicroscopic cementite nodules.—J. P.

The Precipitation of Carbon from α-Iron during Storage. W. Dahl and K. Lücke. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 241–249). The change of carbon content of the solid solution on ageing of carbonyl iron (0·002–0·02% C) at 90–150° C. in the undeformed condition, and after 5% extension, has been followed by electrical resistance measurements. The concentration decreased initially by a parabolic law, *i.e.*, proportional to t^{α}. The value of α for undeformed wire lay between 1·04 and 1·36 as against the 1·5 to be expected from Zener's theory. This discrepancy is explained. If the material was plastically deformed before ageing, there was an accelerated decrease in resistance.—J. P.

Determination of Internal Stresses from X-Ray Lattice Constant Measurements. V. Hauk. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 273–278). Samples of mild steel after different amounts of deformation have been examined by X-rays at various angles to determine lattice constants. It is concluded that after plastic deformation there is a bi-axial state of deformation at the surface; the deformation of the longitudinal component can be regarded as a result of internal stress of the first and second types (Heyn stresses). The internal stresses of the first type, determined by measurements on different lattice planes, were different. The size of the cross-section of the sample over a wide range was without noticeable effect. There was no change of internal stresses of the first and second type after etching away the surface or heating to about 300° C. The results are discussed in relation to those of other workers.—J. P.

Rôle of Strain Energy in Solid Solution Thermodynamics. E. S. Machlin. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200** : *J. Met.*, 1954, **6**, May, Section 2, 592–593). The author presents certain results based on the fact that strain energy arising from solution of out-of-size solute atoms into a solid matrix is free energy and not internal energy, and is almost wholly shear strain energy. An expression for the excess entropy of mixing due to the strain energy is derived.—G. F.

The Production of Single Crystals and Alloys with any Desired Orientation by Solidification at High Temperature. H. Takaki, S. Nakamura, Y. Nakamura, J. Hayashi, K. Furukawa, and M. Aso. (*J. Phys. Soc. Japan*, 1954, **9**, Mar.-Apr. 204–208). [In English]. A method for growing single crystals, evolved from the Bridgman method is described. Single crystals of 3·2% and 4·0% silicon steel, and of pure nickel, 3 mm. in dia. and 25 cm. long have been grown, with the rod axis fixed in any desired crystallographic direction.—J. G. W.

The Austenite Decomposition of Hyper-Eutectoid Manganese Steels. W. Jellinghaus, A. Rose, and H. Holetzko. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 251–261). The isothermal time-temperature-transformation curves of three steels, two containing 3·5% and one 1·8% Mn, have been determined, and the information supplemented by microscopic, X-ray, electrical resistance, and magnetic examinations. The investigations show that ferrite formation and carbide precipitation are in competition with each other. The smaller the temperature difference between the martensite point of the pure austenite and the temperature at which the tests are carried out, the greater is the probability that the residual austenite will form ferrite faster than carbide, at least when nuclei of α-iron are present. This is a result of the shape of the martensite line, which runs to higher carbon contents as temperature falls.—J. P.

A Fundamental Consideration of the Transformation of Austenite in the Pearlite and Intermediate Stages. W. Jellinghaus and E. Houdremont. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 263–269). Transformation behaviour in the pearlite and intermediate stages can be interpreted on the basis of two simultaneous reactions, *viz.*, crystallization of α-iron from the γ-solid solution and carbide precipitation, and the competition between them. Both reactions are influenced by diffusion rates of carbon in α-iron and γ-iron. The effects of temperature and alloying elements on these diffusion processes and rates, on the diffusion of the atoms of the α- and γ-lattices, and on the thermodynamic stability of the carbides are discussed and basic rules are proposed for a general interpretation of transformation behaviour.

The Hardness of Martensite as a Function of Its Carbon Content. M. Sagisman. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 271–272). The microhardness of martensite in carbon steels containing 0·3–1·7% C has been measured and a maximum found at 0·8–1·0%. This maximum cannot be explained by E. Maurer's assumption that the hardness of martensite is due to distortion of the α-iron lattice by carbon atoms. It is assumed that it is caused by some particular transformation such as is indicated by observations on low-carbon iron–nickel alloys.—J. P.

Factors Influencing the Isothermal Transformation of Austenite in the Intermediate Range (Bainite Range). II. O. Schaaber. (*Draht, English ed.*, 1954, Apr., 29–39). Continuation of an earlier paper (*see J. Iron Steel Inst.*, 1954, **178**, Sept., 96). Every irregularity in structure, caused either by incomplete transformation, by excessively long holding before quenching, or by cooling too slowly, considerably lowers the mechanical properties of austempered components, in particular the limit of proportionality, the yield point and the endurance limit of unnotched bars. A method of controlling the power of quenching baths, using a dilatometer, is discussed.—R. A. R.

On the Equilibrium Between Carbon and Oxygen Dissolved in Liquid Iron. P. Vallet. (*Rev. Mét.*, 1954, **51**, Feb., 115–128). A statistical study of the results (at 1540° C.) of Marshall and Chapman (*see J. Iron Steel Inst.*, 1942, **145**, 125A) shows that, contrary to these authors' conclusions, it is permissible to equate activities with concentrations for all oxygen contents and up to at least 2·3% carbon. Causes of scatter in these results are analysed and methods of eliminating the errors suggested.—A. G.

Contribution to the Study of the Transformations Occurring During the Tempering of High-Speed Steel. A. H. Michel and J. Papier. (*Rev. Mét.*, 1954, **51**, June, 425–439). The cause of the two contractions (at 80–160° C. and 260–360° C.) during the tempering of martensitic steels has been investigated, using differential dilatometric and thermo-magnetometric techniques, together with the extraction and chemical and X-ray analysis of precipitated carbides. A hitherto unreported low-temperature partial transformation of residual austenite to bainite has been observed. The form of the two stages of tempering depend on martensite composition, the lower stage disappearing when the martensite is poor in carbon and alloying elements.—A. G.

The Effect of Carbon on the S-Curves of Steels of the CD4 Type. G. Mejnet. (*Rev. Mét.*, 1954, **51**, June, 365–379).

From dilatometric and micrographic studies of chromium–molybdenum steels (type CD4) it is concluded that the Ar_1, Ar_2 and Ar_3 transformation regions are lowered and occur over a wider temperature range as the carbon content increases, and that the incubation period before the precipitation of pro-eutectoid ferrite increases up to the eutectoid point (0·73% C). The total martensite formed on isothermal quenching, below the M_f point increases with percentage carbon but the martensite hardness is unaffected.

Contribution to the Thermodynamics of the Austenite-Martensite Transformation in Iron–Carbon Alloys. O. Krisement, E. Houdremont, and F. Wever. (*Rev. Mét.*, 1954, **51,** June 401–410). A theoretical explanation is advanced for the existence of the M_s temperature, which is in good agreement with experimental and thermodynamic data. Calculations suggest that the internal stresses set up during the formation of martensite are the main cause for the persistance of residual austenite.—A. G.

Carbon Steel. (*Mét. Constr. Mécan.*, 1954, **86,** May, 375–383). The structure and properties of plain carbon steels are discussed in a general way. The crystal structures of iron and iron carbides are explained and the Fe–C diagram is examined. The effect of the rate of cooling on the final structure and properties of the steel is discussed; photomicrographs of various steel structures are given. Carburization and nitration of steel are also considered.—B. G. B.

A Magnetic Method for the Determination of γ-Loops in Binary Iron Alloys and Its Application to the Iron-Silicon System. J. Crangle. (*Brit. J. App. Phys.*, 1954, **5,** Apr., 151–154). Measurements of paramagnetic susceptibility at temperatures above the Curie point provide a new method of phase analysis capable of indicating equilibrium conditions in two phase alloys. Application to the Fe–Si system shows a γ-loop maximum at 2·15% Si, instead of 2·5% Si as previously reported.—J. O. L.

Graphitization of Certain Fe–C–Ti Alloys. A. B. Beach and R. W. Heine. (*Amer. Found. Soc. Preprint* 1, 1954). A study has been made of the graphitization of Fe–C–Ti alloys containing 2·5% C and up to 0·76 Ti, and has shown that titanium promotes graphitization. In view of the instability of cementite in these Fe–C–Ti alloys it is concluded that the Fe–C–Ti diagram of Tofaute and Büttinghaus only represents metastable conditions. In the alloys studied the titanium was combined as carbide, TiC, and sulphide TiS, and was found to have no hardening effect on the ferrite.

CORROSION

The Mechanism of Oxidation and Corrosion Processes in Metals and Alloys. K. Hauffe. (*Z. Metallkunde*, 1953, **44,** Dec., 576–583). An attempt is made to discover to what extent the homogeneous disorder theory of Wagner and Schottky describing the mechanism of metallic oxidation is applicable to the mechanism of corrosion. In the ferrous field the disorder phenomena of FeO and Fe_2O_3 are discussed, followed by a treatment of the oxidation mechanism of iron at high temperatures. The passivation of iron in concentrated sulphuric acid is discussed, and interpreted in terms of the boundary layer theory of Schottky and Spenke, and the theory of oxide film formation developed by Cabrera and Mott.—L. D. H.

Application of Electrochemical Methods to the Study of Corrosion—Attack of Fluorides on Steel. W. Katz and T. Kempf. (*Werkstoffe u. Korrosion*, 1954, **5,** May, 172–177). The corrosion of steel by solutions of various fluorides has been studied in the laboratory by determining potential–current curves. Under certain conditions the fluorides of sodium, potassium, and ammonium induce passivity; hexafluosilicic acid and its salts never do so.—J. C. H.

After Boiler Corrosion. J. J. Maguire. (*Indust. Eng. Chem.*, 1954, **46,** May, 994–997). Methods of preventing corrosion in boiler pipelines and fittings are discussed. A recently applied method is based on the deposition of a film of long chain polar amines on the inside of pipes. These form a protective non-wettable film. Octadecylamine ($C_{18}H_{37}NH_2$) is the amine employed; it is usually processed and emulsified.—R. A. R.

Researches on the Porosity and Permeability to Gases of Iron Oxides and Iron. G. Graue. (*Werkstoffe u. Korrosion*, 1954, **5,** May, 161–167; June, 212–216). This is an experimental study of the porosity of various iron oxides, which has a direct bearing on theories of oxidation and scale formation. By using radioactive substances as indicators, porosity of atomic dimensions has been determined, as distinct from the macro-porosity revealed by Archimedean methods using toluol. γ-Fe_2O_3 formed at low temperatures is full of atomic pores, into which air can diffuse. These pores disappear when the oxide is heated for some time at temperatures of 200° C. or higher, and a transition to α-Fe_2O_3 takes place. The true density of the latter oxide is 5·1. Above 570° C. diffusion of atmospheric oxygen into the oxide becomes possible through another mechanism connected with the large amplitude of the oscillations of the α-Fe_2O_3 lattice. Diffusion of this type into the lattice of metallic iron is possible only at temperatures above 800° C. In the second part of the research, the radioactive methods were applied to study the alteration in the structure of ferric oxide on exposure to air at 50° and 250° C. and to water at 100° C. and the effects of the presence of silica and alumina in the iron oxide of the properties of the mixed oxides. The effect of alumina was in line with its known usefulness in increasing the resistance of iron alloys to oxidation, but that of silica was more complicated.—J. C. H.

The Efficiency of Some Protective Treatments in Preventing the Oxidation of Mild Steel at High Temperatures. A. H. Sully, E. A. Brandes, and R. H. Brown. (*Metallurgia*, 1954, **49,** Apr., 165–168). The results of an investigation into the relative effectiveness of chromizing, aluminium coating, and enamelling in providing protection against oxidation when the steel is heated to 700° C. for 1000 hr. are presented. Shorter exposures at 800 and 900° C. are also discussed.—B. G. B.

Potentials of Iron, 18–8 and Titanium in Passivating Solutions. H. H. Uhlig and A. Geary. (*J. Electrochem. Soc.*, 1954, **101,** May, 215–224). Measurements of potential of iron in chromate solutions suggest that it follows the Langmuir adsorption isotherm. This evidence agrees with a primary mechanism of passivity based on adsorption rather than on the formation of a hydrated oxide film. Passivity of 18/8 stainless steel and titanium in sulphuric acid containing cupric or ferric salts appears to be accompanied by the adsorption of Cu^{2+} and Fe^{3+}. The potentials are irreversible and suggest that chemisorption occurs. The behaviour of 18/8 steel in aerated 4% NaCl solution containing hydroxyl ions was also investigated. Calculated adsorption constants agree qualitatively with values based on chemical properties of metals and adsorbed substances.—A. D. H.

Corrosion of Iron in the Presence of Dispersed and Solid Sulphur. R. B. Seymour, W. R. Pascoe, and R. H. Steiner. (*J. Appl. Chem.*, 1954, **4,** Jan., 11–13). The observation of Farrer and Wormwell that steel is attacked rapidly by aqueous dispersions of sulphur has been confirmed. Corrosion decreases considerably, however, when the pH of the solution is raised to a value of 9 or lowered to a value of 4 and negligible attack was noted when dispersions of commercial sulphur cements were used in place of elementary sulphur.—J. O. L.

Cathodic Protection As Applied to Royal Canadian Naval Vessels in Active Service. K. N. Barnard. (*Chem. Indust.*, 1954, Feb. 13, 172–182). Canadian experience has shown that both active and inactive ships can be given cathodic protection, using magnesium, steel, or graphite anodes according to circumstances. Saving on dry-docking charges as well as on replacements more than recoup the installation costs and increased overall efficiency results from the extension of operational life.—J. O. L.

The Corrosion of Machinery in H.M. Ships. L. Kenworthy. (*J. Appl. Chem.*, 1954, **4,** Mar., 97–106). Problems of corrosion in H.M. ships' machinery change in relation to speed and efficiency, but are now more easily dealt with from accumulated experience. Examples are quoted from a wide range of corrosive influences on a variety of ferrous and non-ferrous components, giving remedial and preventive measures. Two major factors in the problem of corrosion are seawater contamination and 'shut-down' periods.—J. O. L.

Cathodic Protection of Ships and Marine Structures. K. A. Spencer. (*Chem. Indust.*, 1954, June 19, 702–708). The theory of cathodic protection is described and applied to the prevention of external or internal corrosion of ships' bottoms or marine structures. Experience has shown that beneficial results are obtained from such applications, but that casual experimentation may easily lead to greater deterioration.—J. O. L.

Protective Coatings for Ships and Marine Installations. J. C. Hudson. (*Chem. Indust.*, 1954, June 5, 640–651). The influence of composition, design and finish, type of coating, and exposure conditions (*e.g.*, outdoor and indoor atmospheres, fresh and salt water) on the corrosion of structural steelwork is discussed, and the optimum requirements for good protection are assessed, with practical examples.—J. O. L.

The Influence of Antimony in Iron-Saturated Zinc Melts on Their Attack on Iron. D. Horstmann. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 207–213). Tests have shown that the laws governing the attack of pure zinc melts on iron also hold for antimony-bearing zinc. At lower and higher temperatures, the attack follows a parabolic time law. The intermediate temperature range (495–515° C. with pure zinc) in which attack is a linear function of time, is extended by additions of antimony. At the lower and higher temperatures, the rate of attack is determined by diffusion in the Γ-layer. In the intermediate range, the alloy layers break up and float as particles in the zinc bath.—J. P.

The Increased Attack of Zinc on Iron at Temperatures around 500° C. D. Horstmann. (*Arch. Eisenhüttenwesen*, 1954, **25**, May-June, 215–219). Investigations of the δ-ζ transformation in the Fe–Zn system have shown that ζ formation can be easily suppressed and proceeds with great speed only with marked under-cooling. The slower speed of ζ-formation at low under-cooling means that, at temperatures around 500° C., a dense ζ-layer cannot form. At the same time, the δ-layer is attacked by the under-saturated zinc melt. The result is that the alloy layers are extensively ruptured, so that the zinc melt can penetrate to the iron surface, which causes an increased rate of attack.—J. P.

Three Useful Instruments for the Control of Corrosion in the Petroleum Refinery. J. M. Versteeg. (*Metalen*, 1954, **9**, June 30, 191–197). [In Dutch]. The Audigage is a robust ultrasonic battery-fed instrument for measuring wall thicknesses of material not readily accessible for internal inspection. The electromagnetic Probolog is for the periodical control of non-magnetic piping ; it detects reductions in wall thicknesses with an accuracy of ± 5% thus clearly indicating the locations of pitted and uniform corrosion. The Remotomike is an electropneumatic instrument for determining internal corrosion and eccentricity in piping although pitting may be difficult to detect with it if the pits happen to be filled with hard deposits. These instruments are obtainable from America and may be of service in other industries.—F. R. H.

Measured Potentials as Related to Corrosion and Polarization in Local Cells. T. P. May and F. L. LaQue. (*Corrosion*, 1954, **10**, Mar., 91–94). Owing to local cell action, irreversible electrode potentials were found unsuitable as a measure of corrosion rates in sea water. Anodic and cathodic currents were applied in separate experiments to steel in flowing sea water. Polarization curves were constructed from the potentials measured at various current densities. Coupled with corresponding corrosion rates, these potentials permitted the construction of approximate polarization curves for the local anodes and cathodes.—J. F. S.

Effect of Operating Conditions on Corrosion of Hot Water Piping in Buildings. H. L. Shuldener. (*Corrosion*, 1954, **10**, Mar., 85–90). The life of hot water piping can be considerably increased by design, by control of temperature and flow throughout the system, and by good maintenance. Not only joint leaks but corrosion losses will be reduced. Clogging by sediment or corrosion products will thus be lessened. Suggestion for good design, maintenance, and operation are given.—J. F. S.

Sea Water Immersion Trials of Protective Coatings. J. H. Greenblatt. (*Corrosion*, 1954, **10**, Mar., 95–99). Sea-water immersion trials of a variety of types of underwater compositions have shown the superior performance of vinyl finishes, both as protective and antifouling paints. Panel tests, substantiated by shipboard trials, have shown that vinyl finishes can be used on hulls which have a controlled cathodic protection system.—J. F. S.

Some Notes on Hydrogen Blistering. G. A. Marsh. (*Corrosion*, 1954, **10**, Mar., 101–102). Data were obtained on the diffusion of atomic hydrogen through several kinds of steel in acid solutions. Where diffusion occurred, sulphide increased the rate. Sulphide contamination was sometimes difficult to remove.—J. F. S.

Laboratory Methods for Evaluation of Inhibitors for Use in Oil and Gas Wells. E. C. Greco and J. C. Spalding, jun. (*Corrosion*, 1954, **10**, Mar., 103–109). This is a resumé of a report of a technical committee considering standardization of methods of evaluating corrosion inhibitors for oil and gas wells. The methods in use in the U.S.A. are reviewed.—J. F. S.

Electrolytic Corrosion of Iron and Copper. W. F. Higgins. (*Nature*, 1954, **173**, May 22, 994–995). Examination of a brine heating vessel has revealed that in the presence of graphitized cast iron, copper is anodically dissolved, whereas normal cast iron is less noble than copper. Care is therefore necessary when coupling copper pipes to old cast-iron gas and water mains and in other commercial applications.—A. G.

Mechanism of Filiform Corrosion. W. H. Slabaugh and M. Grotheer. (*Indust. Eng. Chem.*, 1954, **46**, May, 1014–1016). Filiform corrosion occurs under various organic films and metal platings and the filament directions are independent of the qualities of the metal substrate. A mechanism is proposed based on the osmotic diffusion of water through the semi-permeable layer on the surface, and possible remedies are suggested.—A. G.

Thermodynamics of Irreversible Processes Applied to Corrosion. P. A. Johnson and A. L. Babb. (*Indust. Eng. Chem.*, 1954, **46**, Mar., 518–523). A comparison has been made of the electrochemical corrosion rates of commercial steel in dilute potassium chloride as determined experimentally and from the equation due to J. M. Pearson ($i_0 = I_p I_q/(I_p + I_q)$, where i_0 is the corrosion current, and I_p, I_q are the external currents at the discontinuities in the cathodic and anodic polarization curves). Agreement within 10% is reported but may be less good with metals other than iron due to an increased coupling effect.—A. G.

Action of Polar Organic Inhibitors in Acid Dissolution of Metals. N. Hackerman and A. C. Makrides. (*Indust. Eng. Chem.*, 1954, **46**, Mar., 523–527). Theories of cathodic and anodic inhibition are discussed and an adsorbtion mechanism postulated for the action of polar organic inhibitors. Applications of the suggested mechanism to various compounds are considered.—A. G.

Stress-Corrosion Cracking in Unalloyed Mild Steel—Caustic Embrittlement. E. Rudberg and R. Arpi. (*Jernkontorets Ann.*, 1954, **138**, (6), 350–382). [In Swedish]. The work of a Swedish committee on stress-corrosion cracking is reviewed and details are given of theories advanced and of suggested test methods. Tests were made using U-bent specimens, the variables studied including: Effect of steel composition, heat-treatment, influence of cold working, and of method of surface finish. The Krupp constant-strain test is compared with three other constant-stress methods used by the committee. Two of these impose a controlled, graded increase in stress and appear very suitable for determining specimen resistance to the combined effects of tensile stress and a corrosive environment.—G. G. K.

The Current Status of Fretting Corrosion. W. E. Campbell. (Symposium on Fretting Corrosion, New York, June 25, 1952: *Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 144, 1953, Aug., 3–23).

Fretting Corrosion Tendencies of Several Combinations of Materials. J. R. McDowell. (Symposium on Fretting Corrosion, New York, June 25, 1952: *Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 144, 1953, Aug., 24–39).

Influence of Fretting Corrosion on the Fatigue Strength of Fitted Members. O. J. Horger. (Symposium on Fretting Corrosion, New York June 25, 1952: *Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 144, 1953, Aug., 40–53).

Effect of Lubricants in Minimizing Fretting Corrosion. E. W. Herbek, jun., and R. F. Strohecker. (Symposium on Fretting Corrosion, New York, June 25, 1952: *Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 144, 1953, Aug., 54–70).

Test Equipment for Evaluating Fretting Corrosion. H. H. Uhlig, W. D. Tierney, and A. McClellan. (Symposium on Fretting Corrosion, New York, June 25, 1952: *Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 144, 1953, Aug., 71–81).

ANALYSIS

The Electrolytic Deposition of Iron As an Analytical Technique. J. O. Lay. (*Metallurgia*, 1953, **48**, Dec., 313–314). Procedures for the electrolytic deposition of iron are examined and the effect of interfering elements is assessed. A technique is recommended which can be employed on a wide variety of materials and confirmatory results are reported.—R. A. R.

Symposium on Fluorescent X-Ray Spectrographic Analysis. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 157, 1954). This symposium was held at the 56th annual meeting of the Society, at Atlantic City, on June 29, 1953, under the sponsorship of Committee E–2 on Emission Spectroscopy. The papers presented were:

Basic Theory and Fundamentals of Fluorescent X-Ray Spectrographic Analysis. H. Friedman, L. S. Birks, and E. J. Brooks. (3–26).

The Correlation between Fluorescent X-Ray Intensity and Chemical Composition. J. Sherman. (27–33).

Use of Multichannel Recording in X-Ray Fluorescent Analysis. M. F. Hasler and J. W. Kemp. (34–42).

Examination of Metallic Materials by X-Ray Emission Spectrography. R. M. Brissey, H. A. Liebhafsky, and H. G. Pfeiffer. (43–56).

An Absolute Method of X-Ray Fluorescence Analysis Applied to Stainless Steels. G. E. Noakes. (57–62).

The Fluorescent X-Ray Spectrographic Analysis of Minerals. H. F. Carl and W. J. Campbell. (63–68).

Index to the Literature on Spectrochemical Analysis, Part III—1946–1950. B. F. Scribner and W. F. Meggers. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 41–c, 1954).

Direct-Reading Metal Spectroscopy with a D.C. Arc. S. C. Baker. (*Brit. J. Appl. Phys.*, 1954, **5**, June, 215–219). Using a wavelength spectrometer adapted for direct-reading by the null indication of a cathode-follower bridge circuit and a D.C. globule arc, a linear relationship between the manganese concentration in steel and the Mn-4754/Fe-5455·6 intensity ratio has been obtained over the range 0·3%–1·3% Mn with a standard deviation of 2%. Photographic methods for Mn-4754/Fe-4707·3 give a standard deviation of 4%. Although the volt-ampere characteristic of the arc is discontinuous, a working curve can be prepared which is parallel to the current axis over the required range.—J. O. L.

HISTORICAL

The Saugus Iron Works Restoration. W. R. McClelland. (*Canad. Min. J.*, 1954, **75**, June, 68–70). The recent restoration of the first iron works on the North American continent is described. The plant dates from 1646, and is situated between Boston and Salem in what is now Massachusetts.

The Iron Plantation. A. C. Bining. (*Steelways*, 1954, **10**, June, 4–7). The author traces the growth and decline of iron plantations in the United States from colonial times until late in the nineteenth century.—L. E. W.

Materials for Large Army Gun Tubes—a History. P. R. Kosting. (*Metal Prog.*, 1954, **65**, May, 90–94, 154–156; June, 91–95). The production of cast iron, wrought iron and brass gun tubes in America during the 19th century is reviewed.

Alexandre Tropenas. E. N. Simons. (*Brit. Steelmaker*, 1954, **20**. June, 204–205). A brief account is given of the life of Alexandre Tropenas and of the development of the Tropenas surface-blown converter.—G. F.

ECONOMICS AND STATISTICS

Iron and Steel. J. H. Thompson. (*Min. J.*, Annual Rev., 1954, 32–33). A brief review of the activities of the iron and steel industry during 1953 in the U.S.A. and Europe is made and some production statistics are presented.—B. G. B.

Tool Steels. (*Brit. Iron Steel Monthly Stat. Bull.*, 1954, **29**, June, 5–9). The characteristics of high-speed and general tool steels and the technique of producing them are discussed with data on British production and exports.—R. A. R.

An Active Half Year. (*Brit. Iron Steel Monthly Stat. Bull.*, 1954, **29**, June, 5–9). The rise in steel production during the first six months of 1954, steel supplies and consumption, export prospects, and home market requirements are briefly reviewed.—V. G.

Raw Materials for the Japanese Iron and Steel Industry. R. C. Whitehead. (*Chem. Eng. Min. Rev.*, 1954, **46**, Mar. 10, 231–233; Apr. 10, 267–270; May 10, 319–322). This review shows that Japan is entirely reliant on imports of ore and coking coal if the present rate of production is to be maintained. Small quantities of good iron ore are available in Malaya and the Philippines at competitive prices.—R. A. R.

Metal Canada. H. McLeod. (*Canad. Metals*, 1954, **17**, May 5, 8–22). A detailed survey of Canadian metallurgical (ferrous and non-ferrous) operations during 1953 is made. Iron ore production increased 23% to 6·5 million tons. Mechanization at the Wabana mine enabled the production to be increased from 1·7 to 2·7 million tons. The iron ore exported to the U.S.A. amounted to 2·065 million tons and 1·205 million tons went to Great Britain. Canadian pig iron production was 3·012 million tons, steel production 4·01 million tons, steel castings 106,000 tons and ingot capacity 4·7 million tons.—B. G. B.

MISCELLANEOUS

New Instruments for the Iron and Steel Industry. (*Found. Trade J.*, 1954, **96**, Apr. 22, 477–479). This is a review of some of the instruments shown at the recent Physical Society exhibition in London. The instruments described include a furnace scanning periscope, a thickness gauge, a liquid metal gauge, a turbine blade-edge microscope, industrial television equipment, and radioactive isotope containers.—B. C. W.

Statistical Control in Metalworking Operations. M. Whyte. (*J. Inst. Metals*, 1954, **82**, Mar., 334–344). In many metalworking processes a quantitative assessment of variability can be used to gain efficiency without fundamental changes in the process. Statistical aspects of sampling are discussed, and the selection, control, and sensitivity of routine tests are considered. A number of applications to specific problems arising in metalworking operations is described.—B. G. B.

Vibration Problems. (*Instruments in Industry*, 1954, **1**, Aug., 81–83). Examples are given of the application of vibration and sound measuring equipment to the solution of works vibration problems.—L. D. H.

Combating the Effects of Noise. W. F. Scholtz. (*Foundry*, 1954, **82**, Apr., 112–113, 186, 188). Details are given of the steps which should be taken to combat the effects of industrial noise. The programme is based on work being carried out at the Allis-Chalmers Manufacturing Co. Some simple methods of noise abatement are considered.—B. C. W.

Improvements in the Water Supply of the Iron and Steel Works of the Bochumer Verein, in Particular that of the Höntrop Division. R. Harr. (*Stahl u. Eisen*, 1954, **74**, July 29, 1006–1010). The new installation for the water supply of the Höntrop works is described. Use is made of circulating water, and wastes from mills and pickling baths are purified, neutralized, and clarified before being re-introduced to the system. Rain water is fed into the circuit and thus the wastage of piped water is to some extent made good. The control system and measures to deal with supply failures are indicated. The new installation has proved successful and similar ones are to be constructed in other plants of the combine.—J. P.

Oxygen in Industry: Increasing Demand in Metallurgical Processes. (*Iron Coal Trades Rev.*, 1954, **169**, July 2, 34–36). A description is given of the new oxygen-producing works at Brinsworth, erected by British Oxygen Co. Ltd. to meet increased demand for oxygen in the Sheffield-Rotherham area.

Current Russian Metallurgical Texts—IV. C. A. Zapffe. (*Metal Progress*, 1954, **65**, May, 125–126, 142–148). A short account of recent Russian technical books is presented. The subjects include forging technology, electric arc welding, heat-treatment, steel casting, and fatigue failure.—B. G. B.

BOOK NOTICES

DEUTSCHE GESELLSCHAFT FÜR CHEMISCHES APPARATEWESEN E.V. "*Dechema-Werkstoff-Tabelle.*" Chemische Beständigkeit der Werkstoffe. 3. Bearbeitung. Folio, loose-leaf. Part 3. Approx. 100 sheets (200 pp.) each. Weinheim-Bergstrasse [1954]: Verlag-Chemie G.m.b.H.

This is the third part of this publication, just reviewed in the *Journal*, 1954, **177**, July, 385; this volume proceeds from *Benzin* (gasoline, motor spirit or petrol) to *1,3-butadien*, by way of such curiosities as *Bierwürze* and *Borneocampher*: the list of substances susceptible or non-susceptible to these remains the same. The explanatory notes seem, in general, fuller and more useful.—J. P. S.

DURRER, ROBERT. "*Verhütten von Eisenerzen.*" 2., neu bearbeitete und erweiterte Auflage. (Stahleisen-Bücher, Band 3). 8vo, pp. xi + 159. Illustrated. Düsseldorf, 1954: Verlag Stahleisen m.b.H.

The appearance of a second edition of Professor Durrer's manual of iron smelting, first published in 1943, shows that it has continued to fill a need, and indeed, coming to the work for the first time, it is not difficult to appreciate why the author's refreshingly different approach to a well-worn subject has won favour. The treatment is commendably terse, though never superficial, and is free from padding. Little or no attempt is made to discuss the operating side of iron smelting and any allusion to plant features is restricted to broadly outlining the construction of the various furnaces used for the different processes of iron smelting today. The book is essentially a well-arranged assemblage of the physical and chemical principles under-lying the winning of iron, in the form of pig, sponge, and bloomery nodules or "Luppen," to use their German name, from ores and other iron-bearing materials.

Opening with an outline of the fundamental principles of the smelting process and of the physical and chemical properties of the chief materials for carrying it out, there follows a section on the production of iron sponge by the Höganäs and Wiberg processes. Next the Krupp-Renn rotary kiln method of direct reduction is examined before the main portion of the work dealing with pig-iron making is broached. Here the ordinary blast-furnace is first considered before undertaking a relatively full treatment of electric smelting—an interesting feature of the book. Minor processes such as the Basset and the Stürzelburg are then dealt with and the effects of blast enrichment by oxygen are considered, these lead to a short section on the low-shaft furnace.

Though generally the author has succeeded admirably in his aims, it might be felt that these should have embraced a consideration of the principles of burden preparation, particularly ore crushing, classifying, concentrating, and the agglomeration of the inherent and consequential "fines" and the influence of these preparatory processes on the technical performance of furnaces. The general make-up of the book is fully up to the standard expected from its publisher.—G. A. V. RUSSELL.

MATHES, KARL P. "*Werkzeugmaschinen für Metallbearbeitung.*" 1. Band. Sma. 8vo. Pp. 100. Illustrated. Berlin, 1954: Walter de Gruyter & Co. (Price DM 2.40).

This little book deals in a broad and undetailed way with the design and development of machine tools; the author is concerned especially with the standardization of types of machine tool, and can point to a satisfactory reduction of the number of types of the same kind of machine, by no less than 75%. The tables and illustrations, except where the latter depict primitive machine tools, do not add much to the book, which is of more value to the economist and the academic student of workshop practice than to anyone else.—J. P. S.

PHYSICAL SOCIETY. "*Rutherford: by Those Who Knew Him.*" 8vo, pp. 70. Illustrated. London, 1954: The Society. (Price 8*s.* 6*d.*)

This volume contains the first five of the Rutherford lectures, given to the Physical Society on various occasions in the last dozen years. All are extremely interesting, in their revelations of the character of an acute, warm-hearted, somewhat tempestuous man who, as Mr. H. R. Robinson, who worked with him in Manchester between 1907 and 1919, says, "had, in spite of the long hours he spent in the laboratory and his study, the fresh skin and clear eye usually associated with an outdoor life"; a man whom Professor M. L. Oliphant describes as the pioneer of the new age of atomic energy. Like Dr. Cockcroft, we may wish that he were alive to deal with the consequences of nuclear fission: he would certainly have brought to them, as he did to all problems up to the very end of his life, a tremendous gusto, an accurately directed energy, and a clear head.

How much of this sharp vision and warm vitality was hereditary may, perhaps, be gathered from the illuminating chapter by Mr. E. Marsden, of the New Zealand Scientific Office; his grandfather was early among the New Zealand pioneers, arriving, with Rutherford's father-to-be, James aged 3½, in 1842, and by the time Ernest Rutherford was born, fourth in a family of twelve, an agricultural community had developed. James was a "bush engineer," wheelwright, engineer, flax-miller and farmer, and it is typical of this community that he, like many another no doubt, could turn his hand to anything, it is no less typical that he should also be musical, and that the community itself should have its own primary and secondary schools. Ernest throve in this atmosphere; he was a remarkable child in remarkable surroundings. He would surely have been remarkable anywhere; he himself was modest, saying that not the ideas of a single man, but the combined wisdom of thousands of men, go to the advancement of science. Yet in things as fundamental as physics, only great men can make great advances; and he was a great and gifted man who applied his gifts in a great fashion.—J. P. S.

REBOUX, P. "*Phénomènes de Fluidisation. Documentation Générale.*" La. 8vo, pp. 165. Illustrated. Paris, 1954: Association Française de Fluidisation. (Price 1800 fr.)

The use of dense-phase fluidization in the petroleum industry for catalytic cracking and hydroforming is now well established. This new technique, which was developed from small-scale experiments to large production units in a few years, has attracted much attention and study, particularly so because of the possibility of its application in both metallurgical and chemical industries. The Association Française de Fluidisation is a committee formed under the ægis of the Union des Industries Chimiques to study the physical mechanisms which play a part in the so-called fluidization of solid particles. The Association, which has drawn its members from both nationalized and private industries, particularly those concerned with fuel or with metallurgical or chemical processes, commissioned Mons. Reboux to review the experimental and theoretical work in this field which has already been published. This volume is the result of Mons. Reboux's bibliographic labours.

After an introduction which covers the general aspects of the phenomena of fluidization, the history of its development and its industrial application, there follows a detailed discussion of the properties of fluid beds. The effect of particle size and shape, gas speed for minimum and maximum fluidization, apparent density and viscosity, homogeneous and heterogeneous fluidization, transport and erosion of solid particles, and internal and external heat exchange are some of the subjects discussed from both the theoretical and practical angles.

Mons. Reboux has done his work well; a mass of data is clearly presented and the review is an extremely valuable addition to the literature of this subject. The use of dense-phase fluidization in the metallurgical and chemical industries has not developed so rapidly as it has in the petroleum industry. Nevertheless, such processes as the calcination of ores, the roasting of sulphides, lime burning, gas-solid catalytic reactions in general and exothermic oxidations in particular all offer interesting possibilities. Some of these processes are already operating on the commercial scale. All concerned with these new developments will find Mons. Reboux's book of great interest and value.—H. L. RILEY.

SEDLACZEK, HERBERT. "*Das Walzen von Edelstählen.*" (Stahleisen-Bücher, Band 11.) 8vo, pp. xii + 246. Illustrated. Düsseldorf, 1954: Verlag Stahleisen m.b.H. (Price DM 26.–).

The literature of iron and steel manufacture is singularly deficient in works of a practical nature dealing with the deformation of ferrous metals. This book, which is based on a series of lectures recently delivered before the Technische Akademie, Wuppertal, Germany, therefore fills a very definite need, although the fact that it appears in German and not in English will unfortunately limit its appeal in so far as Britain is concerned.

The rolling of special steels is not an easy matter to deal with satisfactorily, as the author, if he is to be successful in conveying to his readers a clear picture of his subject, must be familiar not only with the actual rolling of special steels but also with their metallurgy. Herr Sedlaczek possesses this attribute, and the book is written in simple and easily understandable language and is well illustrated with many photographs, diagrams and charts of the high

standard usually associated with German technical publications.

The rolling technique for special steels has been developed in Britain and on the Continent along generally similar lines. In both cases practices have been evolved and perfected in relatively small plants, and there has been little or no interchange of experience until comparatively recently. This book does much to break down these barriers and deals not only with the actual rolling processes but covers in reasonable detail many of the secondary stages of manufacture. As an indication, there are sections covering the choice of type and size of ingot; the conditioning of ingots and billets by machining, scarfing and other means; methods of heating with useful data on rolling temperatures.

The chapters which deal with rolling contain a wealth of information relative to the production of blooms, billets, bars, rods, and flats. Actual roll-pass designs for a number of products are included, and there is much useful detail regarding mill design.

In general, this is a book which will interest both engineers and metallurgists, whether or not they are directly engaged in the production of special steels, and in view of the paucity of such publications it is to be hoped that an English edition will be available in the not too distant future.—J. A. KILBY.

NEW PUBLICATIONS

" 1948–49 *Bibliographic Survey of Corrosion.*" Pp. 346. Houston, Texas, 1954: National Association of Corrosion Engineers. (Price $12.50; to Members of N.A.C.E. $10)

CHARLOT, G. " *Qualitative Inorganic Analysis. A New Physico-Chemical Approach.*" Translated by R. C. Murray. Pp. xi + 356. Illustrated. London, 1954: Methuen and Co., Ltd. (Price 42*s.*)

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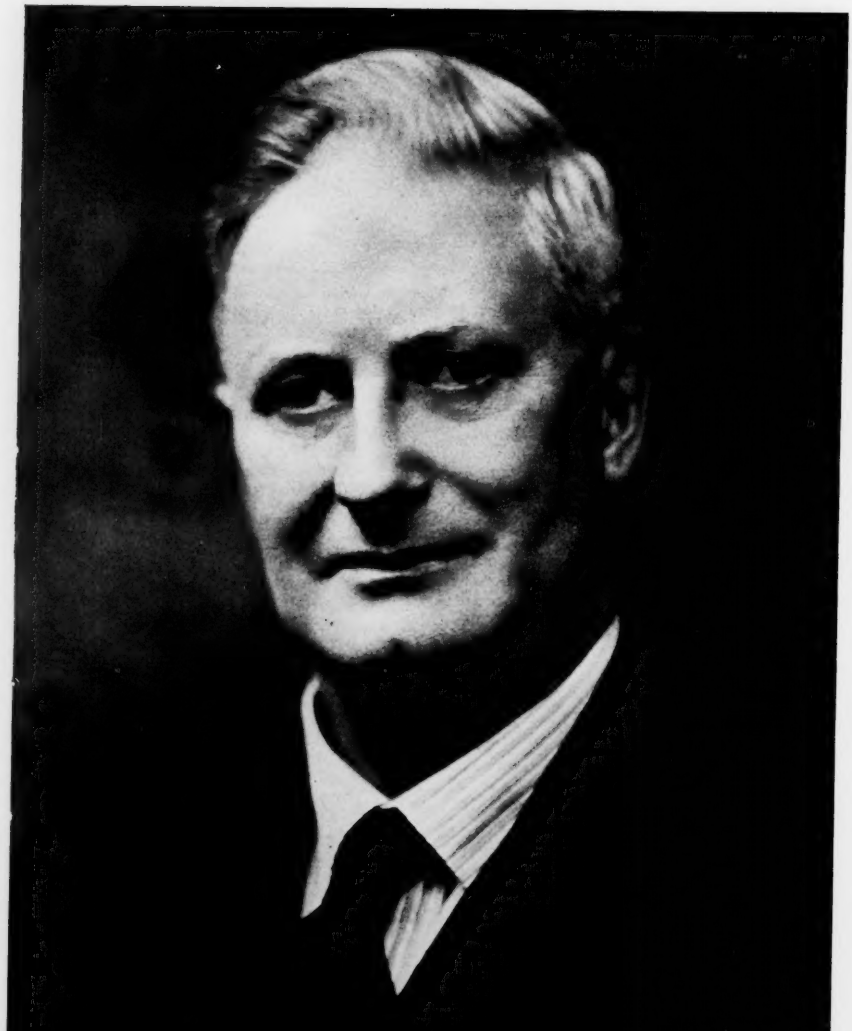

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